MEAT EMULSIONS

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I. INTRODUCTION

Food science is one of the youngest of the sciences. Perhaps one of the youngest major areas in food science is the science of meat emulsion. Although there are written records of sausage as early as 500 B.C., almost all of the published research data on meat emulsions has been

written since 1960. The meat emulsion area is a fertile field for future research which needs to be done by people with a strong background in physical chemistry, biochemistry, flavor chemistry, or food science. Research needs range from basic studies to very applied areas. Much of our knowledge today concerning meat emulsion has been obtained from the use of model systems. Therefore, a relatively large amount of discussion will be included on model systems.

It is gratifying to observe the research interest in meat emulsions in recent years. It is frustrating, however, to find that there is such a large amount of objective physical and chemical values for many ingredients used in nonfood industrial emulsions (from which it is possible to predict what will occur under a given set of conditions in emulsion formation and stability), whereas there is only a very small amount of objective physical and chemical values for the ingredients making up meat emulsions—or even other nonmeat food emulsions. Therefore, much of the theory of meat emulsions must be indirectly obtained from data concerning other food emulsions or basic emulsion theory.

Meat emulsions are very important economically to the meat and food processing industry. As of December 31, 1966, there were 1,951 federally inspected meat plants in the United States. Of this number, 1,332 plants produced only processed meat while 619 plants slaughtered livestock or slaughtered and processed meats. These numbers do not include state and local plants, which would probably outnumber the federally inspected plants. Brown (1965) stated that, according to recent reports, sausage is a two-billion-dollar annual market, and with rapid population increases this market should expand. In 1966 a total of 2,513,885,000 pounds of meat emulsion products were produced in federally inspected plants, a 7.3% increase over the amount produced in 1965. These figures do not include the amount of meat emulsions produced in plants under state and local inspection.

Meat emulsions are generally well accepted in those countries which are not accustomed to eating this type of product. Because of versatility in producing various types of products and because of the types of seasonings which can be used, meat emulsions may be part of the answer to feeding people whose diet is low in protein. The protein may have to be changed to fish (Tankiawa, 1963) or to plant proteins, because of the cost of animal protein in some areas of the world.

II. THEORY OF MEAT EMULSIONS

The definition of an emulsion, which would apply to a meat emulsion, is a two-phase system, consisting of a fairly coarse dispersion of a solid (fat) in a liquid (water) in which the solid is not miscible. The dispersion

must be made with a given amount of shear force, and an emulsifying agent is required to give stability to the emulsion. In meat emulsions the dispersed phase or discontinuous phase is fat; the continuous phase is water (which also contains the various water-soluble components); the emulsifying agent (sometimes termed surfactant or surface-active agent) is the soluble proteins, especially those which are salt-soluble. Emulsions can be complex (Osipow, 1962), that is, a portion of the liquid constituting the external phase may be found dispersed in droplets in the discontinuous phase. However, this condition has not been observed in commercial meat emulsions (Hansen, 1960; Helmer and Saffle, 1963; Borchart *et al.*, 1967).

Osipow (1962) stated that the particle size in an emulsion can be from 0.1 micron to 50 microns. From photomicrographs (Hansen, 1960; Helmer and Saffle, 1963) of actual commercial meat emulsions, the fat particles were much larger than 50 microns; thus on the basis of particle size the meat emulsions could not be considered to be true emulsions. However, recent work of Borchart *et al.* (1967) showed that some of the fat particles were as small as 0.1 micron. A several-thousand-fold difference in size of the fat particle clearly exists, which may tend to decrease the stability of the meat emulsion. No data are available to permit a reasonable estimate of how great an effect this variance in size would have on stability.

The two general types of emulsions are oil-in-water (O/W) or water-in-oil (W/O), with either of the two liquids as the dispersed phase. One physical difference is that a dispersion of oil-in-water produces a creamy texture, whereas a water-in-oil dispersion has a greasy texture. Other common methods of determining which type of emulsion is formed (O/W or W/O) are:

1. Use of a fat dye to stain the fat particle, and observation through a microscope of whether the fat is the continuous or discontinuous phase. With small fat particles and the necessity of using a relatively high light source and high-power magnification, a certain degree of skill must be developed before accurate observations can be made.

2. Placement of a drop of emulsion on a slide and then observation through the microscope while a small drop of water is added and stirred with a pinpoint to see whether the water blends with the emulsion. If the water mixes readily with the emulsion, it is an O/W emulsion. An O/W emulsion will conduct an electrical current, but a W/O will not (it is necessary to keep the amperage low or the emulsion may break, especially an O/W emulsion) Gortner and Gortner, 1950; Clayton, 1954; Becher, 1955, 1965; Lowe, 1955; West and Todd, 1961). Since an O/W emulsion is the only type found in meat emulsions, all of the remaining discussion is concerned with this type.

When a fat is in contact with water, a high interfacial tension is present (measured in dynes/cm). If two liquids are completely soluble in each other, the interfacial tension is zero. When two immiscible liquids are in contact with each other and the interfacial tension is lowered to a very low degree, a spontaneous emulsion will occur (Clayton 1954; Becher, 1955; Lowe, 1955). It is obvious that a meat emulsion is more stable if the interfacial tension is low. Unfortunately, sodium chloride greatly increases the surface and interfacial tension of water. The actual emulsification process requires considerable energy input, resulting in a thermodynamically unstable system. The emulsifying agent reduces the interfacial tension, reducing the energy which must be put into making the emulsion. Reduction by the emulsifying agent of the energy required goes a long way in explaining the formation and stability of an emulsion, but it is scarcely the whole story (Becher, 1955). Emulsifying agents are assigned hydrophilic-lipophilic balance (HLB) values. The main characteristic of an emulsifying agent is that it has affinities for both water and fat when it is absorbed at the interface. These affinities are satisfied when the hydrophilic portion is oriented toward the water and the lyophilic part toward the fat. The lower the HLB value the more lyophilic the emulsifying agent (favoring a W/O emulsion), and the higher the HLB value the more hydrophilic the emulsifier. The HLB numbers which form the better oil-in-water emulsions range from 8 to 18. In the limited amount of work done on meat emulsions, the addition of commercial emulsifiers with HLB values in this range has actually reduced the amount of fat which could be emulsified (Meyer *et al.* 1964). At one time it was thought that O/W and W/O emulsifying agents in combination were antagonistic to each other. However, Becher (1965) and Clayton (1954) have shown that their effect is additive and that a more stable emulsion may be formed by a combination of different emulsifiers. The smaller the dispersed particles the more stable the emulsion, because of the reduction of potential energy, providing there is sufficient emulsifying agent to cover the fat particles. Swift (1965) has pointed out that in a model system the decrease in particle size increases the surface area to such an extent that less fat is emulsified. In an actual meat emulsion, the total amount of salt-soluble protein potentially available is not generally utilized. When an emulsitator machine is used, the fat particle size is made smaller and the emulsion is more stable. No data are available to indicate whether more soluble portein is being extracted and used. The higher the viscosity of the emulsion, the more stable will be the emulsion (Becher, 1965; Clayton, 1954; Lowe, 1955). Sausage emuslions are very viscous (centipoise units ranging from several hundred thousand to millions), and in some cases the viscosity

may be so great that present processing equipment is overloaded, causing an excessive heat build-up. The effect of viscosity on meat emulsion stability has not been studied up to the present. It has been proposed that fine particles (such as finely ground mustard) will stabilize a meat emulsion because they lower the interfacial tension as they adhere to the interface. Kilgore (1935) has clearly demonstrated this in the production of mayonnaise. However, no research data are available to indicate the effects of finely divided inert particles on the stability of meat emulsions.

Very little data are available on the basic theory of meat emulsion. The brief previous discussion was concerned with a very few factors that appear to be important in the formation and stability of meat emulsions. Detailed discussion of the theory of emulsions are found in a number of excellent books, e.g. Clayton (1954) and Becher (1965).

III. MODEL SYSTEMS FOR STUDYING MEAT EMULSIONS

Before many factors which affect the formation and stability of meat emulsions could be determined with reasonable precision, model systems had to be developed. Knowledge on meat emulsions has been obtained with commercial production-type equipment, and more valuable knowledge will undoubtedly be developed in the future with this same equipment. Such equipment, however, has many major disadvantages for studying many of the fundamental factors in meat emulsions. It is very difficult and sometimes impossible to maintain all factors constant except the variable being studied. The model systems now being used have been indispensable in developing much of our knowledge on the effects of pH, types of proteins and fats, shear force, temperature, salt, fillers or binders, fat particle size, prerigor, fresh and frozen meat, ions, and numerous other factors. Perhaps the biggest fault of present-day commercial production type of equipment for obtaining objective fundamental knowledge about meat emulsion is that the equipment is very inefficient, as is discussed in section IV-A of this review. The model systems available also have certain limitations, which are discussed in Section III-E.

A. Model Systems Available

The first model system developed was by Swift *et al.* (1961). The basic method consisted of a one-pint jar in which a meat sample plus 1*M* NaCl solution or a protein extract solution was added to the jar. A specific amount of melted lard was added, and high-speed cutting–mixing (*ca*, 13,000 r.p.m.) was begun with an Omni-mixer. Immediately thereafter, melted lard was added at a specific rate from a graduated

separatory funnel through Tygon tubing into the jar. An O/W emulsion was formed and became increasingly more viscous as lard was added until viscosity suddenly decreased. Addition of fat was immediately terminated. The initial volume of lard added, plus the additional lard withdrawn from the separatory funnel, just exceeding the emulsifying capacity of the meat sample or extract, was recorded.

The basic principles used by Swift *et al.* (1961) in developing their system are, in general, the same for all the model systems now in use. Some workers have referred to their method as being similar to the system of Swift *et al.* (1961) with relatively minor changes (Hegarty *et al.*, 1963). Other workers (Carpenter and Saffle, 1964) have referred to their method as a different system from that of Swift *et al.* (1961). So far, in every case the various research groups using the model-system approach have used equipment of different manufacturers with gross differences in design and shape, temperature rise while making and breaking the emulsion, amount of shear force, rpm's and various other factors. The emulsions formed by these various types of equipment are visually different, and fat particle sizes as judged by photomicrographs are grossly different in many cases. For this review, the method used by various research workers is referred to as their system. This permits an easier and clearer procedure for comparing results among various research groups or individuals. Nevertheless, as implied, some or all of the basic principles of the various systems were first reported by Swift *et al.* (1961), who should be given due credit.

The system of Hegarty *et al.* (1963) involved use of a Lightning stirrer, Model L, equipped with a three-blade propeller and operated at a relatively low speed (1750 rpm). They used protein extracts as the emulsifying agent and soybean oil for the dispersed phase. They expressed their results as grams of oil emulsified per milligram of protein nitrogen in the solution. Besides studying the emulsifying properties of various proteins and other factors, they used the system to study the stability of emulsions. Emulsions for stability tests were prepared with 25 ml of protein solution (0.5 mg of protein nitrogen/ml) and 200 g of soybean oil. When the protein in question would not emulsify 200 g of oil, the amount of oil was reduced to a suitable level. All emulsions were white immediately after preparation, and their stability was determined by noting the time following preparation at which noticeable fat separation occurred.

The system of Carpenter and Saffle (1964) consisted of an Osterizer mixer base for the motor and blades and an inverted pint Ball jar with a 5-mm hole bored in its bottom. Twenty-five ml of protein extract (10 mg/ml) and 50 ml of Wesson oil were emulsified for 30 seconds at 13,400 rpm. Additional oil was added continuously from a graduated

cylinder via a piece of Tygon tubing extended 12mm. through the bottom of the inverted jar. The temperature of the emulsion immediately after breaking was controlled within $\pm$ 1°C by adding oil heated or cooled to a predetermined degree; otherwise, the results were erratic. The pH of the protein extract was always held at a constant for any series of study. No difficulty was encountered by a rigid emulsion resisting mixing near the "end point" necessitating manual assistance of the flow into the blades as reported by Swift *et. al.* (1961) to occur occasionally in their system.

Trautman (1964) used a stainless-steel Waring microblender. Thirty ml of a 1% protein solution (room temperature) or slurry and 5 g of fat at 40°C was poured into the blender. A rubber stopper was placed in the neck of the blender to avoid excessive foaming during the 60 seconds of blending at room temperature. The emulsion was then transferred to 50-ml calibrated conical centrifuge tubes. No data are given as to the rpm's of the system, temperature of the emulsion, or pH of the initial protein solution or slurry. The fat-emulsification capacity of a protein was determined by observing: first, the time after blending at which a discontinuous liquid phase appeared; and second, the rate at which the discontinuous phase increased until a constant volume was obtained. The original report, contains an obvious error in reporting the data. Figure 1 in that paper is a plot of the increase in milliliters of discontinuous phase vs. time after blending. For all of the eight different protein extracts, between 18 and 22 ml of discontinuous phase is reported after varying periods. If an O/W emulsion was formed, these high values could not occur because the fat would be the discontinuous phase and only five ml of fat was emulsified. The values are probably the increase in ml of continuous phase instead of ml discontinuous phase. The only other alternative would be that a W/O emulsion was formed, but in meat emulsions this type is never made. The data in that paper are nevertheless valuable if the words "discontinuous phase" are changed to "continuous phase."

B. The Use of Model Systems to Determine Various Factors Which Affect Meat Emulsions

1. Efficiency of Various Proteins in Emulsifying Fat

One factor which has caused considerable confusion about the efficiency of various proteins in fat emulsification is the definition of salt-soluble and water-soluble proteins. The strict definition of salt-soluble proteins is: those proteins which are soluble in salt solutions and insoluble in pure water; an example is actomyosin. The strict

definition of water-soluble proteins is: those proteins which are soluble in pure water and insoluble in water containing any appreciable amount of salt; an example is many of the sarcoplasmic proteins. A third group of proteins is soluble in either pure water or water containing high concentrations of salt; an example is myoglobin. Most reports on meat emulsions use the term salt-soluble protein to mean those proteins which are salt-soluble plus those proteins which are also water-soluble, and the term water-soluble protein to include those protein which are extractable with water plus those protein which are also salt-soluble.

With one exception, the salt-soluble proteins have been reported by all research workers to be superior to water-soluble protein in the amount of fat which can be emulsified. Hansen (1960) was not able to emulsify any fat with water-soluble proteins but did form emulsions with salt-soluble protein. In that portion of his excellent paper it is impossible to tell what method or system he used. The only information given is that 200 ml of 2% protein solution plus 15 g of clarified pork fat were placed in prechilled (0°C) blender jars and beaten together until 15.6°C was reached. With the system of Swift *et al.* (1961), Hegarty *et al.* (1963), or Carpenter and Saffle (1964) an emulsion would have been formed with the amount of protein and fat which Hansen used. Trautman (1964) failed to emulsify 5 ml of fat with 300 mg of water-soluble protein. Swift (1965) stated that many times that much fat would apparently have been emulsified with the system employed in his laboratory. A point of caution should be considered concerning the "water-soluble protein" which Trautman used. The soluble protein was extracted with 0.67*M* NaCl, centrifuged, filtered, and exhaustively dialyzed against 0.05*M* NaCl to remove the nonprotein nitrogen and render the salt-soluble proteins insoluble. The insoluble salt-soluble proteins were then sedimented by centrifuging, and the supernatant was dialyzed against 0.67*M* NaCl. The proteins termed water-soluble in this case are in reality both water and salt soluble and do not contain any proteins which are soluble only in water or proteins which are soluble only in salt. This extraction procedure has not been used by any other research group working with meat emulsions. Therefore, it is impossible at this time to say with a high degree of certainty whether the fat could have been emulsified with one of the other model systems or whether the soluble proteins in this case have an extremely low emulsifying capacity.

Swift (1965) reported that salt-soluble proteins were 30–400% more effective in emulsification capacity than water-soluble proteins. Carpenter and Saffle (1965) reported that water-soluble proteins were only 70% as efficient in emulsification capacity as salt-soluble proteins. Proteins extracted at pH 7.6 and an ionic strength of 0.05 had a

limiting viscosity number of only 2.75. When this value was applied in the equation of Simha (1940) for estimating molecular shape, a length-to-width ratio of 4:1 was obtained. Thus the water-soluble proteins are almost spherical in shape. The salt-soluble proteins extracted at pH 9.0 and an ionic strength of 0.67 had a length-to-width ratio of 200:1, and when the pH was adjusted to 6.0 the ratio was 175:1. It is obvious that, for a given quantity of protein, the salt-soluble proteins have approximately 50 times as much surface area to surround a fat particle as do the water-soluble-proteins. The correlation between limiting viscosity numbers and emulsification capacity was r = 0.97. In that study the pH of extraction was not the same for water-soluble proteins as for salt-soluble proteins, respectively pH 7.6 vs. pH 9.0. The pH at which the proteins were extracted would probably have an effect on the length-to-width ratio, but it would appear that the ionic strength of the extraction buffer had the major effect on this ratio. Addition of solid sodium chloride to the water-soluble protein solid to a final concentration of 2.5%, resulted in a small increase in their emulsification capacity. A small increase in limiting viscosity number and sulfhydryl group analysis indicated that the presence of salts causes some unfolding of the water-soluble proteins. Titration curves were very similar for both the water-soluble and salt-soluble protein and resembled the characteristic titration of an amino acid. Two sharp declines occurred in titration curves at pH 2–3 and pH 10–12, and a small drop at pH 6–7. According to Szent-Gyorgyi (1951), these drops in the titration curves would correspond to the pK of the carboxyl and amino groups and imidazole ring of histidine, respectively.

Swift and Sulzbacher (1963) found that the emulsification capacity of the water-soluble protein occurs at a maximum pH 5.2 and sharply decreases in alkaline or acidic solutions. They reported that the emulsion capacity of salt-soluble protein solutions was maximum at pH 6.0 to 6.5 and did not change when the pH was increased to 8.0. Their results indicate that, at all pH values, the emulsification capacity of the water-soluble proteins increased with increasing concentrations of sodium chloride. The emulsifying capacity of the salt-soluble proteins was not significantly different (mean values were higher) in 0.3, 0.6, and 1.2*M* NaCl except that, at pH values approaching or lower than pH 5.4, approximating the isoelectric points of the salt-soluble proteins, increasing sodium chloride content produced a significant increase in emulsifying capacity. In the region of this pH, decreased solubility of the proteins would be expected to decrease emulsification capacity. They cited Taylor (1953) that increasing the ionic strength lowers the pH at which proteins attained minimum solubility. The effect of sodium chloride in the pH range of 5.0 to 6.0 can be logically

explained by assuming that an increased concentration of sodium chloride lowered the pH at which the salt-soluble proteins lost solubility; consequently, an increased content of sodium chloride enhanced emulsification capacity by promoting a more thoroughly dispersed protein. Those same researchers added 0.3, 0.6, and 1.0*M* solutions of NaCl to meat samples over the pH range of 4.6 to 8.1. Emulsification capacity increased with pH and concentration of sodium chloride. Those results are probably due primarily to increased extraction of protein because of increased pH and amount of sodium chloride in the solution.

Swift and Sulzbacher (1963) also reported that the emulsification capacity of the proteins in a 0.5*M* solution decreased in the order KSCN, KI, KNO_3, KBr, KCl, and K_2SO_4, or the order of the Hofmeister series. They cited Adams (1941) for the explanation that the spreading of protein films is aided by anions in increasing order Cl^-, Br^-, I^-, and SCN. The effect is attributed to different degrees of unfolding of protein molecules.

From work with pure proteins, Hegarty *et al.* (1963) presented interesting data. The proteins, ranked from greatest emulsifying capacity to least, were as follows: actin in the absence of salt, myosin, actomyosin, sarcoplasmic proteins (water extracted), and actin in 0.3*M* salt. According to Szent-Gyorgyi (1951), actin in water is in the globular, or "G," form and not only is round but is rather solid and hard, to the point of being similar to a ballbearing. When "G-actin" is placed in a low concentration of neutral salt solution, the protein is transformed into a typical fibrous colloid. In a more concentrated salt solution the "F-actin" will set to a gel and liquefy on shaking. In theory, it would appear that actin in a salt solution should be highly superior in emulsification capacity to actin in pure water; however, this apparently is not the case. Swift (1965) states that the fact that actin in salt solution had a poor emulsification capacity is only mildly interesting since there is doubt that much free actin exists in either prerigor or postrigor meat. However, Szent-Gyorgyi (1951) reported that 12–15% of the total protein of a muscle is composed of actin, and in prerigor muscle would be "free" or is easily extracted in water. In postrigor meat there would be very little "free" actin, but, in actual sausage making, using prerigor meat, actin may be an important factor in emulsification.

2. The Effect of Concentration of Protein on Emulsification Capacity

Hegarty *et al.* (1963), Trautman (1964), and Swift (1965) observed a curvilinear relation between the concentration of protein and the emulsifying capacity of several protein or protein extracts studied. Carpenter and Saffle (1964) reported a straight-line relation between

the amount of protein in 25 ml of extract and the amount of fat emulsified. Because of this direct conflict in the research data, Saffle (1966a) increased the concentration of protein in the protein extract and used the system of Carpenter and Saffle (1964) to determine emulsion capacity. When the concentration of salt-soluble protein exceeded 28 mg/ml in the 25 ml of extract used, a curvilinear relation resulted between concentration of salt-soluble protein and amount of fat emulsified. It was observed that the system was overloaded, that is, part of the emulsion remained on the side of the jar and there was incomplete mixing as the "break point" was approached. He then changed the blades from four to eight. A straight-line relation was found between concentration of protein and emulsifying capacity until the concentration exceeded 39 mg/ml in the 25 ml of extract. It was again observed that the system overloaded and complete mixing was not occurring as the "break point" was approached. In all cases the temperature of the broken emulsion was always within $\pm 1°C$ for any one study. This close tolerance on temperature was maintained by cooling or heating the oil as necessary. It is believed that the relation between concentration of soluble protein and emulsion capacity for the model system of Carpenter and Saffle (1964) is a straight-line relation until the system is overloaded. It is impossible to tell from the research literature whether complete mixing of the emulsion occurs as the concentration of protein is increased with the other system described. Swift *et al.* (1961) reported that, with their system, rigid emulsions that resisted mixing formed occasionally near the "end point." In these instances, it was necessary to assist the flow of mixture manually into the blades of the Omni-mixer, using a short section of tubing.

The effect of temperature is discussed more fully in Section III-B-3 of this review. Two different research groups have reported a very high inverse correlation between temperature and the amount of fat emulsified. With the system of Carpenter and Saffle (1964), a rise of 6°–12°C occurs between the beginning of mixing and the time the emulsion breaks. They are the only group which have stated definitely that the temperature of the emulsion at the time that it breaks was held in very close tolerance. When the amount of soluble protein is increased and the rate of addition of fat is constant, the temperature at the time of emulsion break would be higher because additional fat has been added and the system has run longer. A curvilinear relation would occur between the amount of soluble protein and the amount of fat emulsified in the system of Carpenter and Saffle (1964) if the temperature were not controlled. That may be the explanation for the "temperature effect" in some or all of the other systems being used.

3. *Effect of Temperature, Rate of Addition of Fat, and Speed of Mixture*

The temperature of preparing the emulsion under actual sausage making is extremely important. It has been known for many years in the sausage industry that, if the emulsion in the chopper exceeds 15°–22°C an emulsion breakdown will occur. This effect of temperature on actually comminuted sausage has been studied by Hansen (1960) and Helmer and Saffle (1963). The usual practice is to add the fattest material at the end of the chopping procedure.

The comminuted-sausage industry has in recent years changed to much faster chopper times, and the use of emulsitator machines has reduced the fat particle size more than in the past. These aspects are discussed in greater detail in section IV-B of this review. However, data published from the use of model systems have given a better understanding of the effect of temperature, rate of addition of fat, and speed of mixing on the emulsification capacity of proteins, although additional research is needed.

Swift *et al.* (1961) found that the amount of fat emulsified was related inversely and linearly to maximum temperature obtained during emulsification ($r = -0.995$). They stated that, since their emulsion could be cooked to 75°C without any breakdown, heating at temperatures in the range of 18°–46°C should not cause emulsions to break down. It is important to note that the cooking of these emulsions to 75°C was done with no mixing or stirring, whereas the effect of temperature on emulsion breakdown was found in the high-speed mixing procedure. They reported that factors possibly contributing to the unresolved "temperature effect" include: (a) a chain of events leading from increased temperature to decreased surface area, and, consequently, an increased need for stabilizing membranes; (b) denaturation of protein prior to the formation of protective membranes; and (c) formation of altered membranes. Carpenter and Saffle (1964) also found an inverse relation between temperature and the emulsifying capacity of protein ($r = -0.93$). They also were able to cook their emulsions to 68°C without emulsion breakdown. Some possible explanations presented by Carpenter and Saffle for this temperature effect were: (a) the stability of an emulsion is increased with increasing viscosity (an emulsion at high temperatures is less viscous and would be less stable than a more viscous emulsion); (b) although ease of emulsification is promoted at higher temperatures, the oil droplets tend to expand and the surface area is increased; and (c) high temperatures will also promote coalescence of the oil droplets, causing less oil to be emulsified before the capacity of the protein to emulsify is exceeded.

Helmer and Saffle (1963) presented data that protein denaturation was not the cause of the lower emulsification of fat. Parkes (1967) found that he could hold his salt-soluble protein extracts at 38°C for 3 hr without any effect on the amount of fat which could be emulsified. After $3\frac{1}{2}$ hours at 38°C, a sharp decrease occurred in the amount of fat which could be emulsified by the extract. If he held his salt-soluble protein extract at 65°C for even a few minutes, emulsification capacity became nonexistent. This would give support to the theory that denaturation of the protein was not the cause for the decrease in emulsification of the fat in the model systems. The increased temperature effect is probably due to a combination of factors which have been discussed and possible additional factors which have not been studied. Obviously, more research is needed in this area.

Swift *et al.* (1961) added fat at the rate of 0.48, 0.57, 0.77, or 1.05 ml per second. They found a straight-line relation between the amount of fat emulsified and the rate of addition ($r = 0.995$). Their explanation was that the rate at which the protein membranes form can be assumed to be almost "instantaneous," and that the vigorous mixing-stirring more than assured adequate dispersion of fat and intermixing of components. Under these circumstances, rate of emulsification would not be a limiting factor. In this case, increasing the rate of addition of fat would utilize more fully the potential rapid rate of emulsification while tending to reduce progressively the damage to protective membranes from unnecessarily extended mixing. Carpenter and Saffle (1964) added oil at rates varying from 0.21 to 1.56 ml per second. They found a correlation coefficient of $r = 0.209$, which was not statistically significant at the 5% level of probability between rate of addition of oil and amount emulsified. From their results they postulated that the only effect that rate of addition of fat had was when the rate was in excess of the capacity of the mixer or when different rates resulted in different temperatures when the emulsion first broke. In the latter case, the slower addition of oil will cause increased temperature build-up due to longer time of mixing; thus, the amount of fat emulsified will decrease unless the temperature of the emulsion at the time of breakdown is controlled. Those same workers added different amounts of oil initially (before mixing) and then added oil during the mixing process at a constant rate. Their results are presented in Table I. It is obvious from these data (Table I) that a small increase in temperature decreased the amount of oil emulsified. The initial amount of oil added had no effect on the amount emulsified provided the temperature was constant. If the capacity of the emulsion or the mixer was overloaded, in this case 75 ml of oil, no emulsion was formed.

Swift *et al.* (1961) have shown that rate of mixing has a major

TABLE I
INITIAL AMOUNT OF OIL IN MIXER[a]

Initial amount of oil (ml)	ml of Oil emulsified per 100 mg of soluble protein[b]	Final temperature (°C)
25	30.79	31–33
50	33.20	27–28
60	33.20	27–28
75	No emulsion formed	

[a]Data from Carpenter and Saffle (1964).

[b]All values are means of 4 to 6 replications. Twenty-five ml of protein extract contained 11.3 mg of salt-soluble protein per ml.

effect on both the amount of fat emulsified and the character of the emulsion produced. Some of their data were presented in Table II. They reported that the increase in viscosity with increasing rate of shear was associated with decreased particle size. The breaking points of the viscous, but mixable, emulsion prepared at 13,000 rpm were readily detectable. They did not report the temperatures of the emulsion immediately after breaking. It is not possible to determine what effect, if any, temperature may have had on the amount of fat emulsified or the character of the emulsion. Carpenter and Saffle (1964) found a correlation coefficient of $r = -0.986$ between amount of oil emulsified and speed of mixing. Their mixing speeds varied from 9,640 rpm, where 36 ml of oil/100 mg of protein was emulsified, to 20,800 rpm, where 25 ml of oil/100 mg of protein was emulsified. In that work the temperature of the emulsion at the time it broke was within ± 1°C at all of the mixing speeds studied. They stated that the greater shear force dispersed the oil into smaller particles, thereby increasing the surface area of

TABLE II
EFFECT ON EMULSIFYING CAPACITY BY VARYING RATE OF MIXING[a]

Total volume of 1*M* NaCl/2.5 g tissue (ml)	Rate of mixing (rpm)	Emulsifying capacity (ml)	Description of the emulsion
47.5	13,000	142	Viscous, mixable
47.5	9,200	168	Slightly viscous
47.5	6,500	185	Grainy suspension

[a]Data from Swift *et al.* (1961).

the oil to be emulsified by a limited amount of protein. Becher (1965) stated that the emulsification of only 10 cubic centimeters of oil to form droplets of a radius of 0.1 μ created an interfacial area of 300 square meters, which is an increase of a millionfold. Caution should be observed in applying these data to sausage emulsions. Increased chopping of a sausage emulsion will decrease fat particle size but also will increase the amount of protein which is extracted, thus enabling more fat surface area to be covered. This aspect is discussed more fully in Section IV, B of this review. Hegarty *et al.* (1963) used a stirrer speed of 1750 rpm, compared with about 13,000 rpm in the two previous systems. Hegarty and co-workers emulsified more oil per mg of nitrogen or protein by their system than either of the systems of Swift and associates or of Carpenter and Saffle. Pearson *et al.* (1965), using the identical system of Hegarty and co-workers, definitely show by photomicrographs that the fat particles are considerably larger than those shown by the other systems. No data could be found in which a study was conducted to study the stability of a meat emulsion, made with either a model system or actual sausage emulsion, as affected by size of the dispersed phase. Research is needed in this area to answer many questions of importance with regard to actual sausage emulsions and emulsions formed in a model system.

4. Effect of Various Types of Fats and Oils on Emulsion Stability

Investigators have used model systems of melted lard, cottonseed oil, soybean oil, and corn oil. None of the research workers who developed the original systems studied the effect that the various oils or fat might have on the amount which could be emulsified. Christian and Saffle (1967) made an extensive study with 26 different fat and oil samples to determine the amounts which could be emulsified in a model system. In addition, they determined the iodine number, acid number, and specific gravity of each sample and correlated these findings with the amount of sample which could be emulsified. They used the model system and the procedures of Carpenter and Saffle (1964). The only exception to these procedures was that a commercial emulsifying agent, "Alipal CO436" (ammonium salt of the sulfate ester of an alkiphenoxypoly ethyleneoxy ethanol), had to be used for five of the pure (technical-grade) fats or fatty acids which had high melting points. They found (Table III) that more of the shorter-chain saturated fatty acids and triglycerides were emulsified than the longer-chain saturated fatty acids and triglycerides. It was also found that more fatty acids with one double bond were emulsified than fatty acids with two double bonds. These results

TABLE III
AMOUNTS OF PURE TRIGLYCERIDES AND FREE FATTY ACIDS WHICH COULD BE EMULSIFIED IN A MODEL SYSTEM[a,b]

Type of fat or fatty acid	Grams of fatty acids emulsified by 500 mg of protein	Grams of fat and fatty acids emulsified by 500 mg of "Alipal"
Trimyristin	—	725.40
Tripalmatin	—	630.00
Oleic acid	44.50	—
Linoleic acid	41.50	—
Myristic acid	36.76	617.40
Palmitic acid	32.21	572.33
Stearic acid	—	548.10

[a]Data from Christian and Saffle (1967).

[b]All means are significantly different from each other ($P < .05$). Dash indicates no determination was made.

indicated that smaller amounts of saturated fatty acids were emulsified than unsaturated fatty acids with one or two double bonds when the length of the carbon chain was the same.

The amount of various commercial oils which can be emulsified by a specific amount of protein is of interest because of the different types which have been used in the various model systems. The amounts of various oils which could be emulsified were significantly different, but

TABLE IV
AMOUNTS OF VEGETABLE OILS WHICH COULD BE EMULSIFIED IN A MODEL SYSTEM[a]

Type of oil	Grams of oil emulsified by 500 mg of protein[b]	Observed viscosities[b,c]
Olive	70.24	8.5
Corn	67.88	8.5
Cottonseed	65.12	8.5
Peanut	64.66	8.0
Linseed	61.66	6.0
Castor	49.98	6.0

[a]Data from Christian and Saffle (1967).

[b]Any means within each column not connected by the same line are significantly different from each other ($P < .05$).

[c]1 = very low viscosity; 10 = very high viscosity (subjective scores).

the specific amount of any one of the various oils was relatively small, except for castor oil (Table IV). Castor oil was selected because it has a large number of hydroxyl radicals, which may be the reason that considerably less of this oil could be emulsified than the other oils studied. Linseed oil and castor oil formed emulsions which were significantly less viscous just before emulsion breakdown than any of the other oils studied. Although a sharp break point could be observed for these two oils, the break points of the emulsions were not as easily seen as in the case of the other oils. Franzen (1967) found no significant difference in the amounts of coconut oil, linseed oil, and lard which could be emulsified by salt-soluble protein extract from poultry meat in the model system of Carpenter and Saffle (1964). He also found that linseed oil resulted in an emulsion with low viscosity.

The amounts of various animal fats which Christian and Saffle could emulsify by 500 mg of salt-soluble protein is shown in Table V. Significant differences ($P < .05$) were found among the types of fats used. However, from a practical standpoint only a small increase in the fat level could be obtained in actual meat emulsions by selecting the type of fat for the formulation.

TABLE V
AMOUNT OF ANIMAL FATS WHICH COULD BE EMULSIFIED IN A MODEL SYSTEM[a]

Type of fat	Grams of fat emulsified by 500 mg of protein[b]	Observed viscosities[b]
Beef loin	72.08	8.0
Beef flank and cod	71.42	7.0
Pork shoulder	69.86	8.0
Pork back	69.68	7.0
Pork jowl	69.20	8.0
Pork ham	68.94	7.0
Beef kidney knob	68.34	7.0
Beef brisket	68.18	7.0
Rendered chicken	66.69	8.0
Mutton leg	65.86	8.0
Beef chuck	64.20	7.0
Mutton kidney knob	63.93	8.0
Pork leaf	63.45	7.0

[a]Data from Christian and Saffle (1967).

[b]Any means within each column not connected by the same line are not significantly different from each other ($P < 0.05$).

Some questions have been raised as to whether results are comparable when vegetable oil is used in a model system instead of animal fats. Except for castor oil and linseed oil, the amounts of vegetable oil and animal fats emulsified are in the same general range (Tables IV and V).

Christian and Saffle (1967) found a very low correlation between the amount of fat emulsified and acid values, iodine numbers, and specific gravities of the fats and oils studies ($r = 0.12$, 0.06, and 0.06, respectively). Their results indicate that an optimum degree of unsaturation increased the amount of fat emulsified. If partial correlation coefficients had been calculated, a higher relationship among these factors may have been obtained. It is doubtful, however, that the relationship among these various factors would have been high enough to be of any practical value.

C. Extraction of Protein for Use in a Model System

Various factors affect the amount and kind of protein which is extracted from a meat sample. Anderson *et al.* (1963) reported that the addition of small amounts of C_{18} fatty acids reduced the quantity of protein which could be extracted from fish muscle. Saffle and Galbreath (1964), however, found no significant difference in the percent of total protein which was soluble in 3% saline when pork fat was added to extra-lean beef. Mean values for salt-soluble protein, expressed as percent of total protein, for 100, 80, and 60% lean meat were respectively 30.4, 30.0, and 30.4%. The pH of the meat sample had a major influence on the amount of protein which could be extracted. The percent of the total protein of lean cow meat which was salt-soluble at "normal" pH (varied from 5.4 to 5.85) and in samples adjusted to pH 5.5, 6.0, and 6.5 were respectively 33.63, 35.92, 38.89, and 42.35. Any rise in pH would be away from the isoelectric point of most of the meat proteins, and thus would result in an increase in the amount of protein which could be extracted and probably a change in the type of protein. Some research groups have indicated that the pH of the sample was not adjusted before extraction. This would result in considerable variation among various samples in the amount of protein extracted because of the relatively wide variation in "normal" pH among various animals and even among various muscles of the same animal.

Saffle and Galbreath (1964) found that the amount of salt-soluble protein which could be extracted from cow meat frozen for 48 hrs was decreased approximately 9% below that from the unfrozen control. This decrease in extractable protein is probably due to denaturation of the protein by freezing. Those workers reported that when the extraction procedure was rigidly controlled the percent of the total protein which could be extracted varied only a small amount among different

batches of the same type of meat. However, the percent of the total protein which could be extracted among different types of meat varied to a high degree. The practical application of this fact is discussed more fully in Section IV, C of this review.

Saffle and Galbreath (1964) found that the amount of protein which could be extracted was 50% more prerigor than 48 hr postrigor. This is about the same difference reported by Turner and Olson (1959). Bard (1965) reported that the amount of proteins soluble in a 3.9%-salt solution obtained with 15-minutes of extraction time was slightly less than 1.0 g per 100 g of postrigor meat, compared with 3.0 g per 100 g of prerigor meat. He also found that when the extraction time was increased to 15 hr the yield of soluble protein was only slightly less from postrigor meat than from prerigor. His graph indicates that the amount of soluble protein obtained was linearly related to extraction time up to 10 hr. The rate in yield of soluble protein decreased after 10 hr. Trautman (1964) reported that prerigor extracts contained 42% of the total extracted protein as salt-soluble protein, whereas the postrigor extract contained 39% salt-soluble protein. That work indicates that the increase in amount of protein obtained from prerigor meat is due primarily to the increase in proteins which are both water-and-salt-soluble.

Bard (1965) reported unpublished data from Trautman's work comparing various levels of sodium chloride through the range of 0–20% in the aqueous phase. All extractions were performed at 0°C, with a 2:1 ratio of extraction solution to lean muscle tissue. He found a linear relationship between increasing amount of soluble protein extracted and increasing percent of sodium chloride up to 10%. The total amount of protein extracted decreased as the percent sodium chloride increased from 10 to 20%. These data are important not only concerning extraction of protein for a model system but also in the production of commercial meat emulsions, which is discussed in Section IV, C of this review. Bard also reported the relation of extraction temperature to the yield of salt-soluble protein. The extraction procedure to determine temperature effect on soluble protein yield was performed with 3.9% NaCl solution at a ratio of two parts solution to one part lean tissue Extraction time was held constant at 30 minutes. It is observed from his data that at -5°C approximately 4 g and 5 g of salt-soluble protein were respectively extracted per 100 g of pork and beef. However, the amount of salt-soluble protein which could be extracted from pork or beef muscles decreased sharply between -5°C and 3°C. The amount of salt-soluble protein extracted decreased slowly from 3°C to 30°C. At this highest temperature (30°C) only approximately 1 g of salt-soluble protein was extracted from 100 g of

muscle. No explanation is given for the sharp decrease in extractability of salt-soluble protein at the relative low temperature (− 5°C to 3°C).

D. Stability Test For Emulsions in a Model System

All emulsion are unstable, and the time required for the emulsion to break may vary from a few seconds to many years. Much of the work published about model systems has reported emulsifying capacity of the emulsion over only a limited period. The terminology usually used for model systems is that "capacity" is the amount of oil or fat added continuously to the system until the emulsion suddenly breaks. "Stability" of an emulsion is usually defined as the time required for a stable emulsion (a specific amount of fat or oil emulsified by a specific amount of soluble protein) to break (the continuous and discontinuous phases to separate). From a practical sausage-making standpoint, the capacity of various meats to emulsify fat is obvious. However, stability is important only from the time an emulsion is made until it is cooked, which is usually only a very few hours. Additional stability of an emulsion beyond the cooking stage is of no benefit, because the cooked sausage product will not break.

In the research literature only Trautman (1964) and Hegarty *et al.* (1963) have reported stability data on emulsions produced in a model system. Trautman (1964) emulsified only 5 ml of fat in 30 ml of a 1% protein solution and then transferred that emulsion to a 50-ml calibrated conical centrifuge tube. He observed separation of the continuous and discontinuous phases at various periods. Most of his emulsions, made from various soluble proteins, separated immediately, with separation proceeding very rapidly to completion at 30 minutes. One of the exceptions was that emulsions made from prerigor salt-soluble protein did not begin to separate until after 10 hr, and separation was not complete until 22 hr. Under some conditions with this system, it would appear that flocculation, as discussed by Clayton (1954), could occur without true emulsion breakdown, especially since the volume of the dispersed phase is relatively small compared to the larger volume of the continuous phase. When flocculation occurs, the individual fat globules will come to the top surface but not lose their individual identity; thus, true emulsion breakdown has not occurred.

Hegarty *et al.* (1963) emulsified 200 g of oil in 25 ml of "pure" protein solution (0.5 mg of protein nitrogen per ml) and noted the time required for fat separation to occur. The time ranged from 24 hr for some emulsions to over three weeks for other emulsions made with a different protein solution. This method and Trautman's method are qualitative procedures because there is no indication that an emulsion

which requires 48 hr to have fat separation is twice as stable as one in which separation occurs in only 24 hr.

Swift (1965) has stated the importance of estimating both capacity and stability in applying emulsification measurements for the evaluation of meats. He also stated that it would appear advisable to go even further and to determine routinely the stability of heated emulsions as a means of obtaining the most realistic guidance for practical sausage making. Meyer *et al.* (1964), Rongey (1965), and Saffle *et al.* (1967) have each developed a method that uses heat to determine the stability of actual sausage emulsions. It would appear that any one of these methods might be used to determine the stability of emulsion made in a model system. Carpenter and Saffle (1964) reported a very limited amount of data obtained with the procedure of Saffle *et al.* (1967) for predicting the stability of emulsions formed in a model system. No data could be found in the research literature derived from either of the other two methods of determining the stability of emulsions formed in a model system.

E. Limitations of Model Systems

Much of the knowledge concerning meat emulsions has been determined in model systems. There is little doubt that many future studies on meat emulsion will be done in model systems. However, caution should be used when data obtained from a model system are compared with sausage emulsions themselves. A partial list of limitations and precautions relating to emulsion systems are as follows:

Most of the model systems are considerably more efficient than commercial systems used in making meat emulsions. In most of the model systems an emulsion can be formed which can be cooked without a breakdown and has an analysis of less than 1% salt-soluble protein and over 80% fat. In actual meat emulsions a minimum of 9–10% total protein is required to emulsify a maximum of 35–40% fat. Thus, the shear force is considerably greater in model systems than is found in commercial emulsifying equipment. The result is that various factors found advantageous in a model system may have little or no value in the actual production of meat emulsions. The model system uses relatively simple material (extracted protein and fat) whereas meat emulsions are composed of very complex materials. Various methods of extracting protein for use in a model system may result in a gross difference from the protein which is actually utilized in making meat emulsions. Many studies with model systems have been related to the capacity to emulsify fat, and little or no work has been done on the stability of the emulsion through the cooking process. The viscosity of the emulsion formed in a model system

will range from a few hundred to a few thousand centipoises, whereas an actual meat emulsion may exceed several million centipoises. This large difference in viscosity should, according to the theory of emulsions, have a major effect on capacity and stability. Most of the basic principles concerning emulsion (i.e. surface tension, interfacial tension, effect of solutes, fat particle size, surface adsorption, surface-active agents, phase volumes, the chemistry of emulsifying agents, finely divided solids, and hydrophil-lipophil balance) have not been studied either in model systems or in actual meat emulsion. Since little or no information is available on these basic principles, it is quite possible that gross differences may exist between model systems and actual meat emulsion, resulting in many cases of invalid comparisons between the two emulsions.

IV. FACTORS AFFECTING THE PRODUCTION OF MEAT EMULSIONS

A. EQUIPMENT

The basic principle used for preparing meat emulsions in commercial equipment has not changed for several decades. When the equipment was first designed, very little data, if any, were available about meat emulsions. When commercial emulsifying equipment is compared with equipment used in model systems, it is obvious that the equipment used in preparing meat emulsions is inefficient. Emulsion breakdown is one of the most serious and costly technical problems in meat emulsions. From the data obtained from model systems for making emulsion, it is clear that the emulsifying agents (soluble proteins) have many times the potential that is required to produce meat emulsion without having emulsion breakdown. Even so, emulsion breakdown does occur much too frequently in the production of meat emulsion. It is beyond the scope of this review to go into great detail concerning the equipment presently used in the commercial production of meat emulsions. However, a brief description is in order of the most commonly used equipment and the major changes made to the original equipment.

1. Grinders

Grinders are used to cut large pieces of meat into smaller pieces, because some of the emulsifying equipment cannot be used with large pieces of meat. The grinding is done by the meat being moved by a worm through a sharp-edged rib cylinder to a perforated plate. As the meat is pushed through the stationary perforated plate, revolving

knives fitted to the worm cut the meat. The perforated plate has round holes ranging from 35 to 3 mm. Frozen meat or extra large pieces of meat are usually ground twice—first through a plate with large holes, and then through a plate with small holes.

2. Silent Cutters

Up to about 1955, the silent cutter was used to form the meat emulsion. Today, however, it is usually used to reduce the particle size of the meat and fat and as a mixer for all of the ingredients used in the emulsion. The emulsion is then produced by an emulsitator or colloid mill. The general principle of the silent cutter is that the emulsion is placed in a horizontal, round, rotating bowl which passes the meat through rapidly-rotating, vertical knives. A cover protects the knives and keeps the meat in the rotating bowl. The number of knives may vary from two to over a dozen. The capacity of the bowl will vary from 50 pounds to over 700 pounds.

The major changes which have been made in the silent cutters are that the speed of the rotating bowl has been greatly increased, and in many cases two to three different speeds may be selected. The vertical cutting knives have been changed from a relatively soft steel to stainless steel. The cover over the knives has been increased in size. The major advantage for these changes is that the cutting is done much faster. Through the use of stainless-steel knives and a slow speed of rotation, the grinding step can be eliminated in many cases. After the first few revolutions of the bowl the meat is cut fine enough that the speed of the bowl is increased. By increasing the size of the cover over the knives, the emulsion does not fall back on the knives, resulting in less friction and a slow build-up of heat. This would permit longer cutting time to extract more soluble protein, or water may be automatically metered into the bowl, and ice would not have to be used. The disadvantage of stainless-steel knives is that knives are difficult to sharpen, and in most processing plants the stainless-steel knives are so dull that they partially cut and partially mash the meat. With the older, softer steel knives, most sausage makers sharpened and honed the knives at least once a day. The older knives, however, could not cut frozen or unground meat.

3. Roto-Cut Machine

The Roto-Cut machine consists of a vertical rotating bowl or cylinder and a set of rotating knives near the edge of the cylinder. The cylinder rotates 80 to 100 times per minute, and the knives rotate at approximately 2500 times per minute. A set of steel plates located in front of the knives turns the meat over just before it

comes in contact with the knives. A conveyor is raised to load the machine from one side, and the finished product is discharged from the opposite side. When the conveyor is lowered, the product is weighed on the conveyor for the next batch. No research data could be found comparing the various machines. The Roto-Cut machine appears to do an excellent job, although only a small number are in operation today. Some object that the capacity of this machine is too small and the cost relatively high.

4. Colloid Mill

Unfortunately there is no standard nomenclature for a colloid mill, homogenizers, or emulsifier equipment. The terminologies for the machines are often used interchangeably despite gross differences in design. The colloid mills used in the production of meat emulsions obtain their shear force by the product's passing between two corrugated steel face plates. The outside plate is attached to the shaft of a motor with an rpm ranging from 2000 to 5000. The inside face plate is tapered and is stationary while the machine is running. The stationary plate can be raised or lowered, which regulates the clearance between the two plates and thereby regulating the particle size of the finished product. The clearance between the two plates may be regulated to any desired degree within the range of a couple of millimeters to 0.003 mm. The colloid mill can and should be started without any product in it. Little or no heat build-up will occur when the machine is running empty, since the two face plates are not touching each other. The colloid mill for meat emulsions was used first in Europe, and later in the United States, to reduce pork skins and smooth muscle to very small diameter for an ingredient in meat emulsions. It was found that a better texture and a more stable meat emulsion would result if the complete meat emulsion was passed through the colloid mill. The main disadvantage of the colloid mill is the relatively small volume which can be emulsified in a given time compared with other equipment which is available. The colloid mill is usually used only by processors with only a small volume of products.

5. Emulsitator Machine

The terminilogy for this type of machine is most unfortunate, because all emulsifying equipment could be called emulsitators. However, this is the term used for this piece of equipment or it may be called by the manufacturers' trade names. The basic principle of the emulsitator is very similar to a grinder. The perforated plate is in a horizontal position, and the holes in the plate are considerably

smaller than with the grinder. The knives are set to drag slightly over the plate. Adjustment of the knives to the plate is critical and is done with a torsion wrench. A hopper is placed over the knives and plate assembly, and the seal of the hopper to the machine must be air-tight. The emulsion from the silent chopper is placed in the hopper, and the emulsitator is started. As the emulsion passes through the plate, a vacuum is formed which pulls more emulsion to the plate. Many of the new models have two sets of plates and knives. The first plate has larger holes, and the second plate has very fine holes. It is extremely important that the product be in the hopper and packed around the knives of the emulsitator before it is turned on. If that is not done, extreme heat build-up will occur very rapidly, and both the knives and plate will be useless.

6. *Vacuumized Equipment*

Considerable air bubbles are incorporated into the meat, and there a number of reasons for reducing the amount of air in the emulsion. Some silent choppers are operative under vacuum conditions. However, the cost of this type of chopper and the slowdown in total time to emulsify large batches of emulsion have the consequence that this type of chopper is not used widely in the industry.

A few processors place the emulsion in a vacuum mixer. The mixers have two revolving shafts with wing-shaped paddles. The mixers are fitted with a cover which has a gasket around the edge, and a vacuum is applied to remove the air. However, since this adds an additional step which is relatively expensive in cost of equipment and manpower, it is not widely used.

Vacuum chambers are available that are large enough to hold a sausage truck containing 500 to 800 pounds of emulsion. It has been found that an intermittent vacuum is as effective as a continuous vacuum. The vacuum chamber does remove some of the air from the emulsion but it is still not very effective, because the high viscosity of the emulsion and its depth in the truck resist fast removal of air.

Some of the continuous-stuffing machines have a vacuum chamber which remove some of the large air bubbles, but only a relative small percent of air is removed. At least two different machines have been developed to remove air from the emulsion. They are too new for sufficient research data to have been developed on how effective they will be. At present there is no wide use of on-the-line equipment for removal of air from meat emulsions.

B. General Procedures of Commercial Production of Meat Emulsions

Lean meat is first ground by a large grinder. As previously stated (Section IV, A, 2), the grinding may be by-passed and the lean meat added to the newer silent choppers. Ice or water, salt, and seasoning are added to the lean meat, and it is chopped until the temperature is in the range of 4°–8°C. During this chopping period, the muscle cells are broken down and the protein is extracted. Since, at this point, the fatter material has not been added but all of the salt has been added, the percent of sale is considerably higher than in the finished product. Work of Bard (1965) indicates that more protein would be extracted with the higher salt content and that the longer the chopping procedure the more salt-soluble proteins would be extracted. The fatter meat is added after the temperature has risen to 4°−8°C, and the chopping is continued until 10°−12°C is reached, beyond which further chopping would be undesirable. The product from the silent chopper is then passed through an emulsitator, which will result in a 5°–8°C rise in temperature. Many processors are using the silent cutter, basically, to reduce the meat particles to a small size and as a mixer. The total time in the silent cutter will frequently range from three to five minutes. The product is not a stable emulsion until it passes through the emulsitator. Data of Bard (1965) indicate that with a longer chopping time in the silent chopper more salt-soluble protein would be extracted and a more stable emulsion would be formed. The extra time in man-hours and decrease in volume per machine-hour, however, may offset the advantage of a longer chopping period. A few processors are grinding the meat and pass it directly through the emulsitator without using a silent chopper. It would appear that lean with more binding capacity would be required when the silent chopper is by-passed.

Hansen (1960) and Helmer and Saffle (1963) have reported that, if the temperature of the emulsion in the silent chopper was above 16° to 27°C, emulsion breakdown would result. Hansen (1960) stated that the emulsion breakdown at these higher temperatures may be due to denaturation of the protein. Helmer and Saffle (1963) found no evidence that the breakdown was due to denaturation of the protein. They found no difference in the amount of salt-soluble protein which could be extracted, and no differences in paper chromatographs or paper electrophoresis between emulsions chopped at the lower temperature and emulsions chopped at the higher temperature. In addition, they found that emulsions chopped to 32°C and chilled to 4.5°C with dry-ice and then chopped to 16°C were stable. In every case, emulsion chopped to 32°C were unstable. They suggested that the instability of

the emulsions chopped to the higher temperatures was due to a decrease in viscosity and surface tension, and that the mechanical action of the chopper knives forced the fat particles into contact with each other. It should be noted that Hansen and also Helmer and Saffle used pork fat as the major portion of the fat in their emulsions, and used no emulsitator. It is this writer's personal observation that, in making a meat emulsion in which most or all of the fat is from beef or mutton, the temperatures reached in the silent cutter can be higher without emulsion breakdown than when pork fat is included. A possible explanation might be that a higher temperature is required for beef and mutton fat to become as soft as pork fat would be at a lower temperature. It has also been observed in the industry that the temperature of the meat emulsion can be higher in temperature coming from the emulsitator than from the silent cutter before emulsion breakdown. It should be emphasized, however, that these two last aspects have not been studied under closely controlled conditions.

After the meat emulsions have been made, they are stuffed in casing or placed in stainless-steel molds. Smaller-diameter products, such as frankfurters, are stuffed into long casings and linked according to the desired length. In recent years, great advances have been made in faster linking machines. The next step is heat processing of the product. A more detailed discussion of heat processing is given in Section IV, E of this review.

In the production of finished skinless meat emulsion products, such as skinless frankfurters, the product is stuffed in artificial casings and the casings are removed after heat processing by high-speed peeling machines. Removal of the artificial casings is a major problem for most processors at certain times. Some of the factors affecting the peeling characteristics of the product are covered in Section VIII, D of this review.

C. Meat Ingredients Used in Meat Emulsions

One of the major considerations in selecting the various meat ingredients for a meat emulsion is the ability of the meat to "bind" or emulsify fat and retain moisture. It is common in the meat emulsion industry to refer to "high binding," "medium binding," and "low binding" as filler meats. Examples of "high-bind" meat include skeletal muscle meat from bulls, cows, and mutton carcasses. Examples of "medium-binding" meats include cheek meat, veal, and pork trimmings. Examples of "low-binding," or filler, meats include ox lips, tripe, pork stomachs, and partially defatted pork tissue.

A more detailed listing of various meat ingredients can be found elsewhere (Wilson, 1960; American Meat Institute Committee on Textbooks, 1953a, b).

Microbial contamination of meat ingredients is of great importance. Warnecke *et al.* (1966) reported that, with the cooking temperatures employed in their study (68°C, internally), the initial degree of contamination of raw materials had little influence upon the surviving bacterial population level, or on the color of the cooked bologna. However, initial high microbial growth in the raw material had a very detrimental effect on texture, flavor, and overall desirability of the end product, even though the great majority of these organisms were killed during the heat-processing schedule. Work by Niven (1951a) demonstrated that high levels of contaminations of raw material may result in green core development. This problem could be controlled by cooking to a higher internal temperature (Evans and Niven, 1955). Although the discoloration could be controlled by increasing the cooking temperature in the processed product, the effect of initial contamination on flavor was not studied. Watts (1957) and Niven (1951b) reported that the growth of microorganisms in prepackaged processed meat emulsions is related to atmosphere, salt concentration, temperature, and number of microorganisms initially present. When in sufficient numbers, microorganisms can alter the flavor and appearance of the product.

Both fat and water must be added as raw materials for an acceptable meat emulsion. Swift *et al.* (1954) found that increasing the moisture and fat level in bologna resulted in corresponding increases in juiciness and tenderness. Juiciness and tenderness varied more noticeably with changes in moisture content than in fat content. It appeared that additional moisture had a greater effect on juiciness and tenderness than a corresponding increase in fat content. Simon *et al.* (1965) reported that frankfurter toughness-firmness increased as the meat protein content increased. Raising the relative humidity in the smokehouse during processing reduced touchness-firmness of frankfurter. They also stated that when a vacuum was applied during preparation of the frankfurter emulsion, puncture modulus increased in direct relation to the degree of vacuum. Carpenter *et al.* (1966) studied the effect of all beef, all pork, all mutton, and a combination of the skeletal meat from each species and at two fat levels. They found a low relationship between flavor or juiciness on tenderness and the percent fat or moisture. An all-mutton high-fat-level mixture definitely had an objectionable odor and flavor, though none of the panel members identified it as being derived from mutton. Since the fat was 100% mutton fat (a high melting and solidification point) the

frankfurters left a typical residual fat taste in the mouth, which most people find objectionable. It is generally recognized in the meat emulsion industry that an all-beef frankfurter or bologna should not exceed 24–28% fat in the finished product. If the fat content is above this, a "coating of fat" is left in the mouth from eating the product.

One of the newest meat ingredients for meat emulsions is machine-deboned raw broiler necks and/or backs. The deboned product has an analysis of 12–13.5% protein, 67–69% moisture, 16–17% fat, and 1–2% ash (May and Hudspeth, 1966; Saffle, 1966a; Franzen, 1967). The percent of the total protein which is salt-soluble is considerably higher than in skeletal cow meat (May and Hudspeth, 1966; Saffle, 1966a). When compared on a pound-to-pound basis with lean boneless cow meat (18% protein), it is approximately 92% as efficient as the cow meat in emulsifying fat. The ratio of moisture to protein of the deboned broiler meat is slightly in excess of 5:1. In hand-boned broiler meat or beef muscle, the moisture-to-protein ratio is 4:1 or less. The increase in the moisture-to-protein ratio is probably due to mechanical squeezing of some of the moisture and soluble protein from the residue. This would result in higher moisture content and a higher percent of the total protein being soluble. Blackshear *et al.* (1966) found that a taste panel preferred frankfurters of deboned broiler meat plus 13% pork trimmings over frankfurters of any other combination of various meats, including 87% beef and 13% pork trimmings. Those workers pointed out that the same amount of ice was used in each formulation and that the beef and pork frankfurter (which were ranked last) might have been more acceptable if additional ice had been added. It is interesting that no chicken flavor was detected in the machine-boned broiler meat. The reason may be that young broiler meat is mild in flavor, and that the mixing-in of pork trimmings or other meats, plus the addition of frankfurter seasoning, completely masks the chicken flavor. One advantage of this fact is that a number of processing plants are using the boneless broiler meat in replacing some of the more expensive boneless cow or bull meat, and yet the flavor of the finished product has not changed.

1. Constant Emulsification Value for Various Types of Meat

As discussed in Section II, two factors must be considered concerning the ability of a type of meat to emulsify fat: 1) the amount of soluble protein potentially available; and 2) the efficiency of the protein to emulsify fat. Saffle and Galbreath (1964) found that 45.60% of the total protein in pork cheek meat was salt-soluble, and that only 38.16% of the total protein of cow meat was salt-soluble.

Carpenter and Saffle (1964) found that only 23.40 ml of oil could be emulsified per 100 mg of salt-soluble protein from pork cheek meat, compared with 36.64 ml of oil with the same amount of salt-soluble protein from cow meat. It is well known in the meat emulsion industry that boneless cow meat is superior to pork cheek meat in emulsifying fat. This observation can be explained by the fact that although less soluble protein (16%) is extractable from cow meat than from pork cheek meat, the soluble protein from pork cheek is considerably less efficient (23%) than that from cow meat.

Before constant binding values could be developed, two questions had to be answered:

First, under standard conditions, would the percentage of the total protein which could be extracted be a constant among various batches of the same kind of meat? Saffle and Galbreath (1964) found that the percent of the total protein which was salt-soluble varied to only a small degree among the same types of meat but varied greatly among different types of meat. In their preliminary work they found that if they changed the condition for extraction the specific values changed but the percent difference among various types of meat remained the same (i.e. if the volume of 3% salt solution was increased per 25 g of meat, more total protein was extracted but the concentration per milliliter decreased and the percent difference in amount among different types of meat remained the same). When their results were expressed as the percent of the total protein which was salt-soluble, the value was a constant. To determine the potential available salt-soluble protein available for different batches of the same type of meat, it is only necessary to determine the total protein of each batch of meat and then multiply the percent total protein times the constant value for that specific type of meat.

The second question which had to be answered was: would the amount of oil or fat emulsified by 100 mg of salt-soluble protein vary from one batch of meat to another? Carpenter and Saffle (1964) and Carpenter (1964) found that the amount of oil emulsified by 100 mg of salt-soluble protein varied to only a small degree between batches of meat of the same type, but varied greatly among different types of meat. May and Hudspeth (1966) and Hudspeth and May (1967) also found that the percent of the total protein which was salt-soluble and the milliliters of oil emulsified per 100 mg of salt-soluble protein varied only slightly for any one type of poultry meat. However, both the percent of extractable salt-soluble protein and the amount of fat emulsified varied greatly among light and dark meat of turkeys, hens, and broilers, and the dark meat of duck.

Basically, two constants have been obtained.

The first constant is the percent of the total protein which is salt-soluble (which actually makes all of the values on a 100% basis as far as protein is concerned). This constant is an objective measure of the quantity of salt-soluble protein which is potentially available per unit of total protein.

The second constant is the amount of fat which can be emulsified by 100 mg of salt-soluble protein (which actually makes all of the values on a 100% basis as far as protein is concerned). This constant is an objective measure of the efficiency of the salt-soluble protein.

Since both constants are on a 100%-protein basis, they can be multiplied together, and this single value (called constant emulsification values) can be used for each type of meat. In practical use, one can determine from a processor's past records the number of emulsification units necessary to hold a given amount of fat. For a simple example, if a processor's past records showed that he used 50 pounds of 15%-protein boneless cow meat and 50 pounds of 10%-protein pork trimmings and produced a finished product analyzing 30% fat, the total emulsification units he used can be calculated as follows: [0.15 (percent total protein in boneless cow meat) × 14.0 (the constant emulsification value for cow meat) × 50 (pounds of cow meat used)] + [0.10 (percent total protein in pork trimmings) × 13.1 (constant emulsification value for pork trimmings) × 50 (pound of pork trimmings used)] = 170.5 emulsification units had been used to emulsify 30% of fat in the finished product. For formulating a new batch of product to contain 30% fat in the finished product, a minimum of 170.5 emulsification units of bind would be a restriction. The total emulsification units can usually be lowered by small amounts until a slight emulsion breakdown occurs, and then the total emulsification units raised a small amount as a safety factor. These emulsification values were first used in 1964 in a commercial processing plant, with excellent results. A large number of processing plants are presently using them. A full discussion of the constant emulsification units can be found elsewhere (Saffle, 1964; Saffle, 1966b).

2. Prerigor, Postrigor, and Frozen Meat

The use of prerigor meat was a common practice in the United States up until the 1930's or early 1940's. It was realized that prerigor meat had excellent emulsification properties (American Meat Institute Committee on Textbooks, 1953a,b); however, the reason for its superior emulsification was not known. The use of prerigor meat was almost discontinued, for various reasons (increase in refrigeration equipment and labor requirements). Today there is a new interest in

prerigor meat. Turner and Olson (1958), Trautman (1964), and Bard (1965) have all shown prerigor meat to be superior in emulsification properties. Saffle and Galbreath (1964) reported that the amount of salt-soluble protein was 50% greater than from beef at 48 hr postrigor. Acton and Saffle (1967) found that 52.8% more salt-soluble protein could be extracted from prerigor beef than from postrigor meat. More importantly, they found that 60.6% more fat could be emulsified with prerigor salt-soluble protein than with the same amount of postrigor salt-soluble protein. A portion of prerigor meat in coarse-ground cooked sausage products will increase the texture properties, reduce moisture loss, and decrease the rendering of the fat. A similar effect can be obtained by emulsifying approximately 20% of the meat block with ice and salt and adding this material into a mixer with the coarse-ground meat (Saffle, 1966a). There are at least three methods by which prerigor meat can be processed to obtain its superior emulsification value. These methods are discussed in the following section (IV, C, 3).

It is well known within the meat emulsion industry that frozen meat does not have the emulsification capacity of fresh meat. In the United States, frozen lean meat will usually sell for one to five cents less than fresh meat. Saffle and Galbreath (1964) found that the amount of salt-soluble protein which could be extracted was 9% less in frozen meat than in fresh meat. This decrease in extractable salt-soluble protein is probably due to denaturation of the protein. Acton and Saffle (1967) did not find a significant difference between fresh and frozen meat in extractable salt-soluble protein, but found that the extractable salt-soluble protein from frozen meat held slightly less fat than that from fresh meat.

3. Preblending of Meat for Meat Emulsions

Tauber and Lloyd (1946) found a wide variation in the chemical composition of frankfurters obtained from 10 different processors. The range in the analyses was 10.5–15.3% protein, 14.2–35.8% fat, and 52.5–65.4% moisture. Although those workers did not indicate the reasons for this large variation in composition, it is reasonable to believe that some of this variation is due to processors' different beliefs as to what is the best analysis for frankfurters. However, a large part of the variation was probably due to not analyzing the raw ingredients, and the subjective estimate of the amount of fat and lean was inaccurate. In our laboratory, we have found that the analysis of product made by a single processor varies from week to week almost as much as the variation reported by Tauber and Lloyd. *The National*

Provisioner quoted the price of boneless cutter and canner cow meat at 52.5 cents per pound on March 30, 1967. This raw ingredient is used primarily for the emulsification value of its protein. If the boneless cow meat analyzed 18% protein, the cost of one pound of protein would be $2.91. If a processor desired to produce a finished product with 11% protein but actually made a product with 13% protein, the additional cost per pound would be 5.8 cents higher. If the processor's finished product were to have 9% protein, the emulsion would probably break and the cost would be considerably higher.

A few meat processors in the United States are preblending the raw ingredients in large lots (3000 to 12,000 pounds) and determining the analysis of the raw ingredients before the emulsion is made. Most grind the raw material and then mix the material in large mixers. According to the analysis, additional fat or lean is added to arrive at the desired level. In our laboratory we find that processors who preblend have a variance of only $\pm 0.5\%$ for protein and $\pm 1.0\%$ for fat from week to week for each type of product.

Acton and Saffle (1967) have determined the percent of the total protein which is salt-soluble and the milliliters of fat which could be emulsified by 100 mg of salt-soluble protein, and have made actual frankfurter emulsion by the following method: Use prerigor meat in making the emulsion; quickly freeze prerigor meat and use in the frozen state to produce the emulsions (similar to the procedure of Turner and Olson, 1959); grind prerigor meat with ice, salt, nitrite, and ascorbic acid and place in cooler for 12 hours; grind frozen postrigor meat plus ice, salt, nitrite, and ascorbic acid, and place in cooler for 12 hours; grind fresh meat, but all ingredients are added together in the silent chopper. When fresh meat is given a value of 1:00 as to emulsification capacity, the other treatments have the following values: frozen postrigor preblend = 2.00; frozen prerigor = 2.25; fresh preigor = 2.45; and prerigor preblend = 2.73. It is obvious from this data that adding ice and salt to the ground meat plus holding in a cooler for 12 hr resulted in more salt-soluble protein being extracted before the emulsion was made. The value of this meat for emulsifying fat is greatly increased. The disadvantage of using fresh prerigor meat is that the boning operation must be balanced with the emulsion preparation, or the meat will go into rigor and the advantage in emulsification value is lost. In addition, there is not sufficient time to determine the analysis of the prerigor meat. The frozen prerigor meat must be used in the frozen state or it will go into rigor very rapidly when thawed (Crepax and Herion, 1950; Godeaux, 1950; Perry, 1950; Szenlkeralyi, 1957; deFremery and Pool, 1960). The frozen postrigor preblend and the prerigor preblend appear to have a considerable commercial

economic advantage both in increasing the emulsification value and in having sufficient time to determine the chemical analysis before the emulsion is made.

D. Fillers and Binders

Scientific knowledge of the functional use of various fillers and binders is very limited. Most of the fillers and binders are various forms of soybean protein isolates or flour, dried milk products, flour from corn, wheat, barley, rice, and potatoes. These and other non-meat products have been used in the meat emulsion industry for many years. Brown (1965) stated that despite the many additives used in the sausage industry, careful questioning of members of the sausage departments will in most cases reveal no clear-cut reason for their use. Both Wilson (1965) and Brown (1965) have stated that there are no ground rules or guides for evaluating an additive, and an additive can be evaluated only by actual pilot-plant testing of each one. They further stated that if guidelines were available, many proposed new additives could be eliminated without making the first test.

Rongey and Bratzler (1966) substituted 3.5, 10.0, 15.0, and 20% high-temperature-processed nonfat dried milk for part of the meat formula of bologna and found little difference from an all-meat control in percent moisture, percent protein, and seven-day-storage shrink. However, bologna which had 3.5% nonfat dried milk had a higher yield than the control product. Nonfat dried milk increased pH from 6.2 to 6.4. Bologna with 10% nonfat dried milk was only slightly lighter in color, while 15 and 20% levels produced a much lighter-colored product. Tensile strength was maximum with 3.5 and 10% nonfat dried milk. Flavor preference was the same for the all-meat control and the 3.5 and 10% nonfat dried milk products. They reported that 10% soya grits (the only level they used) added to the bologna emulsion resulted in the lowest flavor preference scores. In addition, soya grits at a 10% level produced an inferior product from a standpoint of color, because of the yellow hue. Raymond (1965) studied the effect of 13 different heat-processed nonfat dried milks and their ability to emulsify fat and retain moisture in frankfurters. He found that high-heat-treated milks had the lowest amount of "soluble" protein. However, he found no significant differences among the various processed nonfat dried milks, used at 0, 3.5, 7.0 or 10% levels, in effects on the amount of moisture or fat emulsified in frankfurters. He conducted a large consumer taste panel involving 1,689 individuals to determine the effects of various levels (0, 3.5, 7, and 10%) of nonfat dried milk on the flavor and juiciness of frankfurters. Analysis of variance of the results showed no

significant differences in flavor or juiciness of the frankfurters for any of the levels of nonfat dried milk used in the study. Saffle (1966a) studied the effect of various levels of nonfat dried milk on the flavor, juiciness, and overall acceptability of frankfurters. His meat consisted of boneless cow meat and fat pork trimmings. The frankfurters were processed by conventional methods. A 12-member trained taste panel evaluated the finished product on a 9-point hedonic scale (9, most acceptable). His results are summarized in Table VI. Nonfat dried milk is bland in flavor. No explanation is given for the increased flavor scores when nonfat dried milk is used unless there may be a protein-sugar interaction. There are no research data to substantiate this theory, however. Three of the trained taste-panel members commented that an undesirable sweet taste was detected at the 12% level of nonfat dried milk. It was observed that frankfurters with the higher levels of nonfat dried milk would char or turn black when grilled. The reason is probably the relatively high level of lactose sugar.

Pearson *et al.* (1965) reported that soya sodium proteinate and potassium casinate were most effective as emulsifiers at a high pH (10.5) and tended to have the greatest emulsifying capacities at the lower ionic strength (0.05). Potassium caseinate was a more effective emulsifier than soy sodium proteinate over the entire range of pH values and ionic strengths, especially in water solutions and in the lower pH range. At the lower concentrations, nonfat dried milk had the greatest emulsifying capacity of any protein additives in the approximate pH range of meat (5.4), regardless of ionic strength. It

TABLE VI

MEAN TASTE PANEL SCORES FOR FLAVOR, JUICINESS, AND OVERALL ACCEPTABILITY OF FRANKFURTERS WITH VARIOUS LEVELS OF NONFAT DRIED MILK[a,b]

Level of nonfat dried milk (%)	Flavor	Juiciness	Overall acceptability
0	6.30[c]	5.79[c]	5.54[c]
3	6.81[d]	6.00[d]	5.94[d]
6	6.79[d]	5.99[d]	6.56[e]
9	6.65[d]	6.11[d]	5.89[d]
12	6.37[c]	6.14[d]	5.70[c]

[a]Saffle (1966a).

[b]Any two means not followed by the same letter are significantly different at the 0.05 level of probability.

should be pointed out that most meat emulsions are in the pH range of 5.8 to 6.2. Frank and Circle (1959) produced an all-vegetable product closely resembling fine-cut cooked sausage of the frankfurter and bologna type in appearance, flavor, texture, color, and nutritional value, with isolated soy protein as the sole source of protein. They reported that isolated soy protein changes from a viscous sol to a gel on cooking. In the sol state, soy protein was an excellent emulsifying agent, and in the gel state it acted as a matrix to bind fat, water, and other ingredients. They stated that the final pH of the cooked gel should be in the range of 6.2 to 6.5 for obtaining optimum texture. To obtain this pH they used sodium phosphate. If an excess of phosphate is used, the protein becomes soluble in water, giving too tender a texture and a poor structure in the cooked product. Too low a pH produces a hard and granular product with some loss in binding properties. They reported that some fat improves palatability. However, a considerable variation in fat composition is possible in a matrix with the optimum pH range of 6.2 to 6.5. An acceptable product could be made with a fat content as low as 1.5% or as high as 16%. The final texture of the cooked product was dependent not only on the pH and on the fat content but also on the moisture-to-protein ratio. The optimum moisture-to-protein ratio in the cooked product for the most acceptable texture was in the range of 3.0 to 3.5.

Meyer *et al.* (1964) prepared frankfurter emulsion with the addition of eight commercial food emulsifiers, lecithin, and oleic acid at the level of 0, 0.1, 1.0, and 3%. Higher concentrations of emulsifiers resulted in more rendering of the fat. Emulsifiers with higher hydrophil-lipophil balance (HLB) values caused rendering at lower concentration than emulsifiers with lower HLB values. Lecithin did not improve emulsion stability, and imparted an off flavor to the finished product even when used at a 0.1% level. None of the emulsifiers used were effective except in a single experiment using 3% oleic acid. Although none of the commercial emulsifiers were effective as the control (no emulsifiers added), those workers pointed out that emulsifiers whose normal application is in O/W emulsions resulted in more rendering than emulsifiers normally employed for manufacturing W/O emulsion. Their research indicated that, the later the emulsifier was added in processing, the more stable the emulsion (but not as stable as the controls). This could indicate that the use of an emulsifier was, perhaps, causing such small fat globules that there was not sufficient protein to cover and hold the fat in the product. But the data of their report showed that the lyophilic emulsifiers (thus more fat disintegration) gave the best results (though not as good as in controls). Their possible explanation of this contradiction was that the protein matrix is altered instead of the fat phase.

Therefore, the less time the emulsifier is in contact with the protein the less opportunity for reaction, and the more hydrophilic (and more reactive with the protein-water phase) the poorer the stability of the resulting emulsion. In that study they reported all of their results from a stability test they developed. They stated that the finished franks were peeled and the actual amount of fat rendered from the product was determined by weighing 10 franks, placing in a 70°C 2% saline solution for one minute, drying, and reweighing the franks. They reported that since the stability test was more sensitive to changes in stability, results were reported in milliliters of fat rendered from the product by the stability test. No data are given in this report to indicate how accurate the stability test was for determining actual product breakdown, nor are any data given as to what degree the stability test results were duplicated with the same emulsion.

Franzen (1967) added phospholipid to salt-soluble protein in a model system to determine its effect on the emulsification of oil. His results are summarized in Table VII. It is obvious that the addition of 0.025 g of phospholipid resulted in a large increase in amount of oil which could be emulsified. He gave no explanation as to why a level less than 0.025 g was relatively ineffective or why adding additional phospholipid did not emulsify any more fat.

E. Method of Predicting Heat Emulsion Breakdown

A method of predicting meat emulsion breakdown before the emulsion is cooked is useful in commercial operations and for research purposes. Rongey (1965) stated that a rapid method is useful in

TABLE VII
EFFECT OF PHOSPHOLIPID ON THE QUANTITY OF OIL EMULSIFIED[a]

g Phospholipid added to initial oil aliquot	ml of Oil emulsified/ 100 mg protein
0.000	28.8
0.005	29.6
0.015	30.1
0.025	40.4
0.035	40.3
0.050	40.4
0.075	40.9

[a]Data from Franzen (1967).

commercial operations to evaluate specific batches of emulsions when their binding quality is questionable, thus reducing the amount of rework and second-grade product produced. He also stated that such a method is useful as a routine test to ensure quality control, and that the technique enables one to check the operations involved in emulsion preparation and to pinpoint specific areas that may be causing excessive emulsion breakdown.

Meyer *et al.* (1964) developed a rapid method for predicting meat emulsion breakdown. The basic procedure is to place uncooked emulsion in a hand stuffer and then transfer 25 g of emulsion to stainless-steel tubes. The tubes are centrifuged five minutes at 1000 × G, and then subjected to a boiling-water bath for five minutes. The rendered fat and juice are decanted into a graduated 15-ml centrifuge tube, and the milliliters of fat and juice are recorded. The procedure appears to be simple, rapid, and inexpensive. Unfortunately, those workers gave no data to indicate the repeatability of results on duplicate determinations of the same emulsion, or any data to indicate how much fat or juice would have to separate to indicate a broken emulsion.

Rongey (1965) developed a method in which the apparatus consists of a special centrifuge tube which has a large upper chamber fused to a small graduated lower chamber. A fritted-glass disc is placed at the junction of these chambers. The sample rests on the disc, and the juice and fat that cook out are permitted to drain into the lower chamber. Special precautions must be taken in filling the apparatus to ensure that no air pockets are incorporated, or the test will be void. The apparatus is heated at 71°C for 30 min in water-bath and then tempered in another water-bath at 44°C for 10 min. The apparatus is centrifuged for 5–10 min. The amount of juice and fat can be read from the graduated lower portion of the tube, and the results can be expressed as percent juice separated, percent fat separated, or percent total liquid separated. Rongey stated that one of the desirable characteristics of the test is that a poor emulsion is not erroneously accepted as being good; a good emulsion may, however, be rejected as being bad (because of air pockets). Conventional emulsions show a range between duplicates, usually within 1%. Generally, values for fully prepared emulsions are scored as follows:

Total separation, %	*Emulsion quality rating*
Up to 15	Good
15 to 20	Fair
Over 20	Likely to develop fat caps

In addition to predicting meat emulsion stability, a correlation coefficient of 0.71 was established between amount of separation and

TABLE VIII
RESULTS OF EMULSION STABILITY TEST[a]

Condition	Number of emulsions in various stability ranges		
	0.0–0.4% fat released	0.4–0.8% fat released	0.8% fat released
Stable	118	1	0
Very slightly broken	1	12	0
Slightly broken	2	23	0
Broken	0	1	4
Very broken	0	1	19
Extremely broken	0	0	11

[a]Data from Saffle *et al.* (1967).

processing shrinkage. That worker also found that slurries could be made up and the test procedure could be used to evaluate nonmeat binders, various types of meat, fat, or protein extracts as to their ability to bind fat and water.

Saffle *et al.* (1967) developed a rapid procedure for determining the stability of a meat emulsion. A 9-g sample of the uncooked emulsion is placed in a modified Paley fat bottle, and the bottle is placed in a water bath at 70°C and cooked for 30 minutes. The bottles are filled with 70°C water, centrifuged for 2 min at approximately 1000 × G, and tempered for 2 min in a 70°C water bath. The percent fat released is read directly from the stem of the Paley fat bottle. Their results are summarized in Table VIII. As to repeatability between duplicate determinations on the same emulsion, there was never more than 0.1% difference in fat released providing that not more than 0.8% was released. If more than 0.8% fat was released, repeatability between Paley bottles of the same emulsion was poor (i.e. if one bottle showed 2.5% fat released, the second one might range as high as 10% released). In both cases, however, a bad emulsion breakdown was indicated. The identical stability test of Saffle *et al.* (1967) was also used to a limited extent in determining the stability of an emulsion in a model system (Carpenter and Saffle, 1964).

F. TEMPERATURES AND HUMIDITIES IN HEAT PROCESSING MEAT EMULSIONS

There are no uniform heat-processing schedules in the meat emulsion industry. However, a common heat-processing schedule is to start the smokehouse temperature at 60°C and raise it 5°C every

15 minutes until 82°C is obtained. The relative humidity may range from less than 30% to above 80%. The product remains in the smokehouse until an internal product temperature of 66–69°C is obtained. Many processors will follow this general schedule until the internal temperature of the product is 61–63°C, and finish the heating with either a hot-water spray or with steam. After the product is sprayed with hot water for approximately 1 min to remove any surface fat, it is sprayed with cold water for 5–7 min to reduce internal temperature to 32°C. The product is then placed in a cooler. Many processors are increasing the internal temperature of their product in the smokehouse; one major processor cooks to an internal temperature of 82°C.

Saffle *et al.* (1967) have stated that there is a great need for research on heat processing of meat emulsion because of the large increase in BTU's as temperature and relative humidity increase. They cited the example that at 82°C and a relative humidity of 40%, there is 0.15 pound of water vapor per pound of dry air and only 225 BTU. At the same temperature (82°C) but 80% relative humidity, there is 0.45 pound of water vapor per pound of dry air and 525 BTU, or more than double the amount of heat at the same temperature. In conventional steam cooking of frankfurters, there would be in excess of 20,000 BTU per pound of dry air.

Saffle *et al.* (1967) studied the effects of six different heat-and-relative-humidity treatments on the stability, shrinkage, color uniformity, color intensity, and peeling ease of frankfurters. The extremes in heat treatments ranged from 99°C with 94% relative humidity, to a starting temperature of 60°C and the temperature increased uniformly to 82°C over a 35-min period and then remain constant at 82°C while the relative humidity remained constant at 40%. The temperature was recorded in the center of the frankfurter, 1 mm beneath the surface of the frankfurter, and 1 mm outside the surface of the frankfurter. The time required to obtain an interior temperature of 68°C ranged from 4 min for the high-temperature-relative-humidity treatment to 70 min for the lowest-temperature-relative-humidity treatment. They found that the higher the humidity and temperature, the greater was the possibility of emulsion breakdown, especially with marginal formulation. Although a meat emulsion can be broken in the smokehouse by extremely rapid heating schedules, it is not as critical as most sausage makers generally believe. With extremely rapid heating schedules, none of the methods for predicting emulsion breakdown are as accurate as they would be with more "normal" heat-processing schedules. The higher temperature and humidity treatments resulted in lower color intensity and less uniformity of color. No significant differences were found for panel peeling scores among the six treat-

ments, but the mean panel scores were greater for the three lower heat-humidity treatments. Shrinkage was greatest in frankfurters processed at the lowest temperature and lowest humidity. The frankfurters processed at the highest temperature and highest humidity lost less than 1% in processing, but lost an additional 5.38% in the following 24 hr of storage. It was observed that the high-humidity and high-temperature treatments resulted in a frankfurter with a thinner and more tender "skin" than the low-humidity and low-temperature frankfurter, which is in agreement with Simon *et al.* (1965).

Borchart *et al.* (1967) used electron microscopy to study both uncooked and cooked meat emulsions. In the uncooked emulsion, the fat micelles were surrounded with protein, which is in agreement with observations of other research groups (Hansen, 1960; Helmer and Saffle, 1963; Swift *et al.*, 1961). However, two important changes were noted for the thermally processed emulsion: First, the membrane surrounding the fat micelles had been disrupted, resulting in a number of definite pores or openings. Secondly, the continuous phase of the emulsion had been severely altered by thermal processing. The matrix appeared highly disrupted, with the protein being coagulated into dense irregular zones. However, the heated emulsion showed no evidence of "greasing out." They did not study when the protein membrane was broken during heat processing or why there was no evidence of fat rendering from the product after the membrane was broken. This leads to the pure speculation that when the membrane was broken, the matrix was too viscous or had "set up" to the point that the fat was "trapped" and could not come to the surface.

Some meat emulsion products are stuffed in fibrous casing or metal forms and cooked in water, such as liver sausage. Kramlick (1965) found that to reduce the chances of emulsion breakdown, the cook-water temperature should be started at relatively low and raised slowly so as not to have too great a spread between the temperatures of the water and of the product. Since the product is cooked in water, the heat transfer would be considerably faster than in a smokehouse. It is pure speculation, but results of Borchart *et al.* (1967) indicating that the protein membrane around the fat particle is broken in cooked emulsions may explain why borderline emulsion will break either in a rapid-heating-schedule smokehouse or in high-temperature water cooking. If the protein membrane was broken before the matrix had thickened or "set up," fat would be able to come to the surface of the product. Kramlick (1965) also found that as the internal temperature of liver sausage increased the color also turned darker, approaching at 94°C the faded color associated with old product.

G. Linear Programming for Meat Emulsion Formulation

Clithero (1961), Snyder and French (1963), Armbruster and Snyder (1964), and Saffle (1966b) have reported on the use of high-speed computers for formulation of meat emulsions. It is beyond the scope of this review to go into a lengthy discussion of linear programming for sausage emulsions. It is the intent to present a general concept as to the value of this powerful analytical tool to both management and production people in the meat emulsion industry. A number of excellent books are available on the subject.

Anyone not working in the meat emulsion area might wonder why linear programming is of great benefit in sausage formulation. However, there are 35 to 50 or more possible raw ingredients which might be used in a meat emulsion. Each is priced differently, and each has different amounts of fat, protein, moisture, emulsification values, and color values. Each meat emulsion has 12 to 20 or more constraints or restrictions, such as minimum and maximum fat, minimum protein, maximum water to be added, and minimum emulsification units and color units, as well as a number of restrictions for label requirements. With so many variables in ingredients and product restrictions, it is not feasible to hand calculate a least-cost formulation for a given quality of finished product.

The output reports from the computer will, of course, give the pounds of each specific raw material to be used and the cost for the emulsion. However, other reports which are obtained may be more important to management than the average savings of two to three cents per pound of finished product. These reports include the check report which gives the minimum and maximum values for each restriction which was assigned to the product and the solution value. Cost of ingredient restrictions report gives management an exact cost figure for each ingredient restriction. For example, if the emulsification unit restriction was solved at the minimum restriction, a cost of 0.1525 per unit of emulsification value might be shown. This would tell management that if the emulsification units were lowered by one unit, 0.1525 cent per pound of product could be saved. This might indicate that with better quality control and research the minimum emulsification units might be lowered by 10 units and result in an increased saving of 1.525 cents per pound of product. However, if the ingredient restriction was solved somewhere between the minimum and maximum restriction, a 0.0000 cost would appear. This would indicate to management that no saving would result from research to find a way of increasing or decreasing this restriction, or the restriction could be increased to a degree without additional cost and a more uniform product produced.

TABLE IX
COST-RANGE REPORT—INGREDIENTS USED[a]

Ingredient	Cost	Highest cost	High variable	Lowest cost	Low variable
Bull meat	0.5400	0.5600	Cow meat	0.5100	80% lean pork
50% lean pork	0.2000	0.2150	Pork jowls	0.1950	Pork jowls
Beef cheek meat	0.3675	0.3700	Pork cheek	0.3550	80% lean pork
Pork jowls	0.1300	0.1600	50% Lean pork	0.1150	50% lean pork
80% Lean pork	0.4000	0.4050	50% Lean pork	0.3750	Beef cheek

[a]Unpublished data. (Saffle, 1966a).

Part of a cost-range report might appear as is shown in Table IX.

The data in Table IX are valuable to management. It gives only those ingredients used in the formulation. It can easily be seen that bull meat will remain at the same level as long as the price does not go below 51 cents per pound. This tells management that it can pay up to 56 cents for bull meat and the same amount will be used, or if they have an extra supply of bull meat it should not be sold for less than 56 cents since it can be used more profitably in their own product. Caution should be exercised in using the high variable and low variable values. If the bull meat cost goes above 56 cents per pound, the high variable tells what ingredient will enter the formulation. However, it is usually not a straight pound-for-pound change, and the linear program should be rerun. If the cost of bull meat falls below 51 cents a pound, more bull meat will be used and it will replace part or all of the 80% lean pork (low variable). Again, however, it is usually not a straight pound-for-pound change, and the linear program should be rerun. Similar types of changes will apply to the other ingredients in Table IX. The second part of the cost-range report is concerned with

TABLE X
COST-RANGE REPORT—INGREDIENTS NOT USED[a]

Ingredient	Market cost/pound	Penalty/pound if used	Highest feasible price to pay/pound
Cow meat	0.5200	0.0200	0.5000
Shank meat	0.5100	0.0351	0.4749
Pork neckbone trim	0.3700	0.0025	0.3675
Pork cheek	0.3900	0.0150	0.3750

[a]Unpublished data (Saffle, 1966a).

the ingredients not used in the formulation. Part of the second part of the cost-range report would look like that shown in Table X.

The penalty-cost figures show how much the formulation cost would increase if an ingredient were forced into the formulation. For example, for each pound of cow meat used in the formulation, the total cost of the formulation would increase two cents. The information in Table X quickly shows management that if cow meat can be purchased at a price up to 50 cents per pound, it is a good buy. If a supply of cow meat is owned, it is best to sell it at a price of 50 cents or more.

H. Fish Sausage

The author of this review is not familiar with fish sausage. A detailed description of the processing of this product is given by Tanikawa (1963). It is believed, however, that a very brief review of the process should be included in this review on meat emulsion. Tanikawa (1963) reported that the consumption of fish sausage and fish ham has greatly increased in Japan. In 1962, 114,125 tons of the product was consumed. He stated that white-fleshed fish are cleaned, filetted, crushed, and then soaked to remove fat, blood, and dust and to bleach the flesh. Potassium nitrite or sodium nitrite is added to red-flesh fish. Salt is added to the fish during the grinding process to increase the fish meat adhesiveness. Vegetable oil, seasoning, and coloring material are added. Powdered starch is also added to adjust the elasticity of the finished product. The mixture is stuffed in rubber film casings and cooked at 85–87°C in continuous cookers. The cooked product is cooled in continuous water coolers. When the casings become wrinkled, the wrinkles are removed by soaking the cooled sausage in boiling water for one minute. The finished fish sausages in their casings are packaged in cellophane.

Tanikawa (1963) stated that big red-fleshed fish are used as raw material for fish ham. He reported that these fish are not used in sausage, because they are not suitable as "binding meat" and are generally weak in elasticity after processing.

V. Texture of Meat Emulsions

A. Methods of Measuring Texture

Swift and Ellis (1957) constructed a device to measure the tensile strength or cohesiveness of bologna. A wooden platform was connected to a vertical rod, 6mm in diameter, which was connected to a wooden

block (5 mm wide and 2·6 cm long). The wooden block came in contact with a slice of bologna. A beaker was placed on the wooden platform, and sand was added at a uniform rate through a funnel and a 5·2-cm length of rubber tubing. A clamp was attached to the tubing to control the flow of the sand. The weight of the beaker and sand, in grams, at the breaking point of the strip of bologna was recorded. The procedure was replicated five times, and the average value was termed the tensile-strength value. No correlations were given between this objective method of measurement and taste-panel scores. Rongey and Bratzler (1966) modified the apparatus of Swift and Ellis (1957). All block surfaces were rounded, weight was added as water rather than sand, and a 2-kg weight was used to hold the bologna strips. The strips of bologna were 22 mm long and 5 mm thick, and were cut from 10 consecutive slices. Tensile strength was expressed as the average weight in grams required to break the bologna strip.

Hashimoto *et al.* (1959) developed a device to measure the elasticity of sausage. A strip of sausage was cut 9 × 9 × 45 mm and fixed between two clamps. One of the clamps was turned until breakage occurred. The amount of "twisting" or "turning" of the clamp was recorded. No data were presented comparing findings with taste-panel scores.

Simon *et al.* (1965) developed an apparatus to specifically measure frankfurter texture. The apparatus consists of a constant driving mechanism (5·0 inches/minute), a force transducer (balance counter-weight system), a compression transducer (gear train), and an incisor-type probe. The apparatus has been named the Carbide penetrometer. Correlation coefficients with taste-panel tenderness scores range from −0·795 to −0·837.

Carpenter *et al.* (1966) correlated the Warner-Bratzler shear, the L.E.E.-Kramer shear, and taste-panel tenderness scores for frankfurters. The correlation coefficient for taste-panel tenderness scores was −0·22 with the Warner-Bratzler shear value and −0·20 with the L.E.E.-Kramer shear value. These low values clearly indicate that both of these shears are of little value in determining the tenderness of frankfurters.

B. Factors Affecting Texture

Swift *et al.* (1954) reported that increasing fat or moisture increased both texture or tenderness and juiciness. Simon *et al.* (1965) reported that frankfurter toughness-firmness increased as the meat protein content increased. Raising the relative humidity in the smokehouse

reduced toughness-firmness. When a vacuum was applied during preparation of the frankfurter emulsion, puncture modulus values increased in direct relation to the degree of vacuum. The influence of several types of equipment used for sausage preparation was evaluated and found to have no significant effect on frankfurter texture. They stated that the fact that panel scores for the whole frankfurter were quite similar to those for the skin (the outside portion of a skinless frankfurter) alone, implied that the tenderness of a frankfurter was judged primarily as a function of its surface property.

Carpenter *et al.* (1966) found that all-pork frankfurters lacked the texture of all-beef or all-mutton or various combination of beef, mutton, and pork. Rongey and Bratzler (1966) stated that the use of 50% pork hearts in a bologna formulation reduced the product tensile strength. Blackshear *et al.* (1966) reported that frankfurters made with chicken hearts plus fat pork trimmings or with gizzards plus fat pork trimmings were not acceptable because of flavor characteristics and, in the case of gizzards, texture characteristics.

Swift and Ellis (1957) reported that adding phosphates to bologna emulsion increases the tensile strength of the finished product.

Simon *et al.* (1965) reported that the force to puncture decreased as the temperature of the finished frankfurter was raised from 0° to 21°C, and was essentially constant from 21° to 49°C. The corresponding compression values increased linearly with increase in frankfurter temperature. Tauber and Lloyd (1946) reported that frankfurters lost very little of their solid content when recooked for the consumer. A large portion of the frankfurter remained intact even after drastic boiling procedures. However, those workers did not imply in any way that drastic boiling procedures should be used.

VI. COLOR OF MEAT EMULSIONS

Except with a very few specialty products, meat emulsions are cured. It is beyond the scope of this paper to go into the details on the chemistry of meat pigment. A number of excellent reviews are available; one of the more recent ones is by Fox (1966). We will consider very briefly the overall reaction for obtaining nitrosylhemochrome, and some of the processing variables which affect the formation of the pigment.

Nitrate must be reduced to nitrite by bacteria over a period before it can affect the color of the meat. Since most meat emulsions are heat processed the same day they are made, nitrate will not have any

effect on the formation of nitrosylhemochrome. Through a series of reactions, sodium nitrite will produce nitric oxide. The nitric oxide will oxidize the heme pigment and form nitrosylmetmyoglobin (brown in color). Nitrosylmetmyoglobin is then reduced to nitrosylmyoglobin (pink in color) and when heated converted to the more stable nitrosylhemochrome (pink in color). These reactions are speeded up in the presence of a reducing agent such as ascorbic acid and low pH. However, if the pH is low when the emulsion is being formed, less salt-soluble protein will be extracted and less fat can be emulsified. Increase in temperature will increase the chemical reactions, providing the temperature is not too great as to denature the heme pigments.

Palmer *et al.* (1961) reported that bologna containing internal dye appeared more attractive or leaner than uncolored bologna. Colored bologna outsold uncolored bologna. Among uncolored samples the two higher protein levels appeared more attractive, or leaner, than lower-protein bologna. Adding color to the lower-protein bologna increased attractiveness more than did increasing protein content. Level of protein did not influence consumer preference as determined by sales test. In light-induced fading studies, colored bologna retained acceptable color or attractiveness significantly longer than uncolored bologna. Protein level influenced light-induced fading only slightly; higher protein levels were somewhat less subject to fading. Added color began to mask flavor, aroma, and bacteriological deterioration of the bologna by the 16th day of storage at 3°C, and possibly as soon as the 13th day. Most state and federal meat inspections do not permit internal dyes or artificial color material in meat emulsion. Saffle (1966a) found that dyes in heat-processed meat emulsions can easily be determined by making a water extract and observing for color after the extract is filtered. Nitrosylhemochrome is not water-soluble, but the dyes are. Dehydrated beet power is frequently used illegally in fresh meats. Saffle (1966a) reported that it could be detected, even when used in small amounts, by making a slurry containing two parts of water to one part of meat, filtering, and adding 1 ml of 10% TCA to 5 ml of the filtrate. The TCA will precipitate the heme pigment of the meat and will not precipitate the soluble beet powder. The color of the solution can be observed, or a quantitative procedure can be used by reading optical density spectrophotometrically at 538 mμ.

Tauber and Simon (1963) reported that approximately 86–93% of the total pigment in commercial frankfurters was found to have reacted to form nitric oxide myochromogen (nitrosylhemochrome). Similar variations were observed in frankfurters prepared in the laboratory from different meat formulations. In a controlled atmosphere, the rate and extent of cured-meat pigment formed was dependent upon the time

and temperature at which the frankfurters were processed. Cured color developed more rapidly in frankfurters heated at 99°C than at 77°C. However, in rapid heat processing by steam cooking only 48–63% of the total pigment was converted to nitrosylhemochrome. Steaming the frankfurters after they had obtained a temperature of 76°C resulted in a pink internal color similar to that of frankfurters which were not steamed. However, the steamed product appeared paler on the surface than did the unsteamed product, probably because of dilution of the pigment by steam processing. They also reported that using a vacuum on the emulsion prior to heating markedly accelerated color development. Praizler (1957) also demonstrated that subjecting a meat emulsion to a vacuum resulted in more rapid color development. Saffle *et al.* (1967) has also shown that less cured color intensity and unformity was obtained in rapidly heated frankfurters than in slower-processed frankfurters.

Chipley and Saffle (1967) dipped stuffed frankfurters before heat processing into various acids, and found that the surface pigment was converted to nitrosylmyoglobin within 5 to 10 min for some of the acids. The acids which were most effective were 5% phosphoric or 5% citric acid for an immersion time of 30 sec. Color was more intense in the acid-treated frankfurters than the controls over a 14-day storage period.

Sair (1965) reported that adding glucono delta lactone to a sausage emulsion did not lower the pH of the emulsion while it was being made. In the presence of heat and moisture, however, glucono delta lactone hydrolyzes very rapidly to gluconic acid. Gluconic acid lowers the pH and increases the speed for producing the cured-meat color. He stated that the use of lactones plus ascorbates in meat emulsions will permit frankfurters to be placed in a 139°C smokehouse and complete the heat-processing time in only 10 min or less. Glucono delta lactone is used in meat emulsions in the United States to some extent, though no published research data on its use could be found.

VII. CASINGS FOR MEAT EMULSIONS

A. Natural Casings

The digestive canals of hogs, cattle, and sheep were used almost exclusively as containers or casings for sausage products up until about 1925. It is believed by some people that the natural casing is more permeable to smoke and moisture and results in a better-flavored product. However, no research data could be found to indicate that

this belief is true. Some products have always been sold in natural casings, and there is a great resistance to changing to other types of casings. Natural casings are relatively expensive, and the amount of natural casings available today is inadequate for the amount of sausage products produced.

The sources of various types of casings from hogs are stomach, bladder, intestines, and bung. The sources from cattle includes weasand (esophagus), bladder, and intestines. The source from lamb is only the intestine. In the United States the natural casings from hogs and cattle are produced and processed domestically. However, most of the natural casings from sheep are imported.

The processing, cleaning, curing, grading, and type of product stuffed in the various natural casings are given a complete chapter elsewhere (American Meat Institute Committee on Textbooks, 1953b).

B. Synthetic Casings

Synthetic casings have many advantages over natural casings. They are uniform in size and can be made for specific types of products in which a high or low degree of stretch is desired, or they can be made very permeable or impermeable to moisture, or if needed can be produced to be heat-sealed. Although many different types are available, most could be grouped in one of five categories:

First are the small-diameter regenerated cellulose tubes (made from cotton linters), which have been manufactured in shirred form. The casings are designed to give maximum uniformity in diameter. They are used principally for the manufacture of skinless frankfurters.

Second are the large-diameter cullulose casings, designed to give maximum uniformity in diameter, less stretch, and more squarely shaped ends. A large number of meat emulsion products are stuffed in this type of casing. The diameter is usually 26–36 cm.

Third are the fibrous casings, designed as a special tough casing to give extremely uniform finished-product diameter. These casings are used in the manufacture of large sausages (long pieces for slicing) and wire cage loaves.

Fourth are special fibrous casings which have been treated to make them less permeable to moisture and air. They provide less cooking loss, but are not suitable for making products which require smoking. These casings are used for Braunschweiger, liver sausage, and jellied loaves.

Fifth are casings which are seamless tubing designed to give maximum moisture resistance. These casings are tough and have

considerable elasticity. They are used primarily for preprocessed products such as meat-emulsion loaves.

C. Edible Collagen Casings

This type of casing is relatively new to the industry. The basic starting material is animal collagen, which is reconstituted into a highly purified, uniform casing. It is designed primarily to be used in place of natural casings. Up until the present time they have been used mostly for fresh pork sausage. However, they are now available to a limited extent for products such as frankfurters. Meat-emulsion products stuffed in this type of casing looks very much like the product would look in natural casings.

D. Factors Affecting the Removal of Casings from Frankfurters

One of the major technical problems in the meat emulsion industry is removal of the artificial casing in the production of skinless frankfurters. This is especially true with today's high-speed peeling machines.

Saffle *et al.* (1964a) found that both protein and fat migrate to the surface of the frankfurter during heat processing. The soluble protein which comes to the surface is coagulated by heat and forms the smooth surface necessary for good peeling characteristics. The amount of fat coming to the surface is small (the emulsions were stable and showed no evidence of any emulsion break) but is an important factor after the smooth protein surface has been formed. Frankfurters containing only pork fat had better peeling scores than frankfurters containing only beef fat. The amount of fat coming to the surface was greater in frankfurters containing pork fat, probably because of a higher amount of free fatty acid and/or lower melting point for the pork fat. Frankfurters stuffed in 21-mm casings and processed with low initial smokehouse temperatures were superior in ease of peeling to frankfurters processed with high initial temperatures. The reason, it is believed, is that a better smooth protein surface is formed at the lower initial temperatures. With the treatment involving high initial smokehouse temperature, frankfurters stuffed in 30-mm casings peeled better than those stuffed in 21-mm casings at low initial temperature. Collagen added in the form of pork skins, plus processing at low initial smokehouse temperature, resulted in the poorest-peeling frankfurters. This is probably due to the collagen being changed to

gelatin, which would stick to the casing. However, frankfurters containing pork skins and processed at high initial smokehouse temperatures peeled well. This may be explained by the fact that collagen when first heated will shrink and become hard before it is converted to gelatin. With the high initial temperature, the collagen was probably never converted to gelatin.

Saffle *et al.* (1964b) reported that the moisture of the surface is only 68% of that of the center of the same frankfurter immediately after coming from the smokehouse. Frankfurters are extremely hard to peel immediately after heat processing unless placed in a water or brine solution or placed in a high-humidity cooler. Peeling ease was highly significantly better for frankfurters held in high-humidity coolers than for those held at lower humidities. Frankfurters held at 15°C had significantly higher peeling scores than those held at either 10°C or 5°C. However, no studies were made to determine the shelf life of the frankfurters held at the higher temperatures. Corn syrup with a dextrose equivalent of 52 used at the level of 2% of the meat block resulted in peeling characteristics superior ($p < \cdot 01$) to those with either higher or lower dextrose equivalents. The explanation is that, as the DE increases, the degree of hygroscopicity increases; thus, more moisture is removed from the air, forming a film of moisture between the casing and the smooth surface of the frankfurter. However, there is a tendency for adhesiveness to increase as DE increases, which reduces peeling ease at high-DE levels.

Chipley and Saffle (1967) found that dipping the frankfurters in 5% phosphoric acid for 30 seconds or 5% citric acid for either 30 or 90 seconds before heat processing increased the peeling ease of the frankfurter. The frankfurter could be hand-peeled before heat processing after the acid treatment. The acid apparently coagulated a smooth surface of protein on the surface. A solution of 5% acetic acid and 5% and 20% liquid smoke increased peeling ease but was not as effective as phosphoric and citric acid.

VIII. ADDITIONAL RESEARCH NEEDS

Many of the needs for research in specific areas have been emphasized in various sections of this chapter. Some of these are worthy of reiteration, and additional needs are emphasized.

Before meat emulsion formation and stability can be more completely understood and the area approaches "pure" science, a large number of basic studies must be made to determine the effects on each component in a meat emulsion of absorption, surface tension, interfacial tension, particle size, HLB numbers, proper phase-volume ratio,

viscosity, and various ions. In addition, the interrelations of these factors must be understood. Obviously, this is a huge task.

Some type of guideline needs to be developed so that it is possible to predict the effect that many nonmeat additives will have on the formation and stability of meat emulsions.

At this point, scant data indicate that many well-known commercial emulsifiers which form O/W emulsions in other foods have actually decreased the amount of fat which can be emulsified in meat emulsions. This is an odd fact and should be studied in considerably more detail.

Many production people believe that the heating of a meat emulsion is highly critical to its stability. With the limited amount of data available today, there is a strong indication that an emulsion can be broken with improper heating, but this factor is not as critical as once believed.

From the data contained from model systems, it is obvious that the emulsification equipment now used is inefficient. This area is wide open for engineers and food scientists to develop new and fresh ideas in this field.

With increasing population and relative decreasing amounts of animal protein, it would be wise not only to be concerned with meat emulsion but to think of the area as protein emulsions. The possibility of using larger quantities of plant protein is relatively new, and opens a challenging field.

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